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TRAMWAY SYSTEMS
TRAMWAY TRACKS
TRAMWAY OVERHEAD WORK
TRAMWAY CARS AND EQUIPMENT
BRAKES AND BRAKE RIGGING
TRAMWAY MOTORS AND CONTROLLERS
DIRECT-CURRENT RAILWAYS
ALTERNATING-CURRENT RAILWAYS
ELECTRIC SIGNALLING ON RAILWAYS

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TRAMWAY SYSTEMS

CONSTRUCTION AND EQUIPMENT

DEVELOPMENT OF TRAMWAYS

HISTORICAL

1. Owing to the rapid growth of towns and cities, the economical and rapid transportation of passengers is a matter of great importance. In cities like London, Glasgow, and Manchester, the demand for travelling facilities during the hours when the people are going to or from their places of business is so great as to be almost impossible to meet. But the electric tramways have done much toward meeting this demand, especially for short distances; for distances greater than 4 or 5 miles, however, the steam and electric railways are preferred, because of the speed limitations of the tramways due to their running in the streets.

2. **Early Tramways.**—The first electric tramway was laid down by Messrs. Siemens & Halske at the Berlin Agricultural Exhibition in 1879. It consisted of a four-wheeled electric locomotive, drawing three small open cars that carried six passengers each. The locomotive was driven by means of a ring-wound geared motor, the current being collected from a central *third rail*; the two running rails acted as return conductors. It drew the train round a part of the Exhibition at a speed of 7 miles an hour.

The first permanent tramway was built by the same firm in Berlin, in 1881. The track was $1\frac{1}{2}$ miles long, had a gauge of 1 metre, and the car carried 26 passengers at a normal speed of 13 miles an hour. The running rails and opposite wheels were insulated, for one rail acted as a feeder and the other rail as a return conductor. The motor weighed $\frac{1}{2}$ ton and developed $5\frac{1}{2}$ horsepower with a working pressure of 90 to 100 volts. The car and passengers weighed about 5 tons. This system was in operation until 1893, when it was superseded by the *overhead system*.

3. The first electric tramway in Great Britain was built by Magnus Volk at Brighton, in 1883. The current for the motors was collected from two insulated running rails at a pressure of 160 volts. This tramway is still in operation, but the current is now carried by a third rail, the two running rails acting as a return. In the same year, Messrs. Siemens Brothers built a 6-mile tramway at Portrush, Ireland, on the third-rail principle. The generating plant was driven by water turbines, making this the first electric-traction plant to be driven by water-power.

The first street tramway in England was constructed by Holroyd Smith along the sea front at Blackpool in 1884. This tramway, built on the *conduit system*, was about 3 miles long, and had a working pressure of 230 volts. Owing to various difficulties with this early type of conduit, and to the entrance of large quantities of water and sand into the duct, resulting in bad contact, the conduit system has been replaced by an overhead trolley.

4. American engineers began to turn their attention to electric traction in the early eighties. In 1883, Messrs. Bentley & Knight started an experimental tramway in Cleveland on a modified *trolley system*. The first tramway in America to use the modern trolley principle was constructed by Leo Daft in Baltimore, in 1885; a third rail was laid along the greater part of the line, however, and the trolley was used only at the road crossings and stopping places. At about the same time an overhead trolley system was shown by Van Depoele at the Toronto Exhibition.

5. **Tramways and Light Railways Acts.**—In England, tramway development was very slow from 1885 up to the early nineties, when the Leeds and South Staffordshire tramway systems were opened. This delay was due partly to the opposition of local authorities and partly to the great expense and onerous conditions imposed on tramways which were constructed under the Tramways Act of 1870, a special Act of Parliament being necessary for each project. The passing of the Light Railways Act in 1896 reduced the difficulty and the cost of obtaining powers to construct new tramways. Since that time, the development of electric tramways in the British Isles has been so rapid that at present about 3,000 miles has been constructed. Under this Act, tramways and light railways are broadly classified together. Thus, as far as the actual method of construction is concerned, an electric light railway may be in some instances merely an electric tramway constructed under the Light Railways Act of 1896.

POWER SUPPLY

6. **Choice of Motive Power.**—Electricity is now generally conceded to be the most convenient and economical power for the operation of street tramways. It is superior to horse, steam, and cable haulage, both as regards flexibility and cheapness of operation. Cable traction shows certain advantages in very hilly localities, but for general purposes electricity has the field practically to itself.

7. **Transmission and Distribution.**—Up to the present time, electric tramcars have been driven almost exclusively on the *direct-current system*; that is, the current supplied to the cars is direct, whether the current supplied from the generating station is direct or alternating. Where considerable power must be transmitted over long distances, alternating current is used for the transmission at high pressure, but it is transformed to low pressure and converted to direct current before being supplied to the cars. Where the distance of transmission is not very great, direct current may be supplied from the generating station; in this case, the use of alternating current is unnecessary.

8. The direct-current series motor is admirably adapted for traction work, and the principal reason why alternating current has not been used to any extent for tramways is that no equally suitable alternating-current motor has been available. The alternating-current induction motor is essentially a constant-speed machine, whereas the characteristics of a traction motor must include variable speed, large starting torque, and decreasing torque with increasing speed. The characteristics of the single-phase commutator motor are very similar to the series-wound direct-current motor. Certain conditions may arise in the future, in particular cases, which may make it desirable to use alternating current for tramway work, as it is already in use for railway work; at present, only direct-current apparatus and systems are standardized for tramway use, and the difficulty of changing over to alternating-current standards must considerably delay any change of system.

9. **Voltage of Supply.**—The maximum voltage at which current is supplied to the working conductor is fixed by the Board of Trade at 550 volts, although permission is granted to generate at any pressure up to 650 volts, in order to compensate for the drop in the feeder system. On most tramways, the average voltage of the working conductor is 500 volts.

METHODS OF CURRENT COLLECTION

OVERHEAD SYSTEM

10. **Alternative Systems.**—The most common method of supplying current to the car is by means of an overhead conductor, from which current is taken by means of a pole attached to the car; this is called the **overhead**, or **trolley**, **system**. The overhead conductor is known as the **trolley wire**. A method which makes use of underground conductors in a conduit, and supplies current to the car by means of a contact plough passing through a slot in the road surface, is called the **conduit system**. In the **surface-contact system**, current is supplied to a series of

contact studs placed between the tracks. These studs are so constructed that when the car passes over them they are made alive and current is collected from them by means of a *contact skate* carried on the car. A fourth method is by means of **storage batteries** carried on the car ; in this case no conductors between the power station and the cars are necessary. Lastly, a third rail may be fixed by the side of the track rails ; this third rail takes the place of the trolley wire in the overhead system. This is known as the **third-rail system** and is suitable only for private rights-of-way. Examples of third-rail tramways are the Snaefell mountain line and some cases of pier railways at watering places.

11. Advantages of the Overhead System.—The overhead system is more widely used than any of the others, as it is both cheap and efficient. The cost of the line equipment is from one-half or less to two-thirds of that of other systems, while the cars and collecting arrangements are simpler and the leakage current less than in the conduit or surface-contact system. Some objection to it was raised on account of the unsightliness of the poles and the danger of falling wires ; but the public soon became accustomed to the poles, while during 14 years the only serious accident that has taken place was caused by telephone wires falling and making contact with the trolley wires. Since this accident, the Board of Trade regulations covering the use of guard wires for the protection of telephone and telegraph circuits have been revised, so that there is now practically no danger from this cause. There is a certain amount of danger if a trolley wire breaks and falls to the ground, but the custom of anchoring the trolley wire at those points where breaks are especially liable to occur has minimized the danger from this source by preventing these wires from falling when broken.

12. Diagram of Overhead System.—A diagram of a simple tramway system, with an overhead trolley conductor supplied from a direct-current generator, is given in Fig. 1. The positive terminal of the generator is connected, through the switchboard, to the overhead trolley wire, and the negative terminal is connected to the rail return, the path of the current being indicated by the arrows. Current is collected by each moving car by

means of the trolley pole carried on the roof of the car. This simple arrangement was not devised without considerable experi-

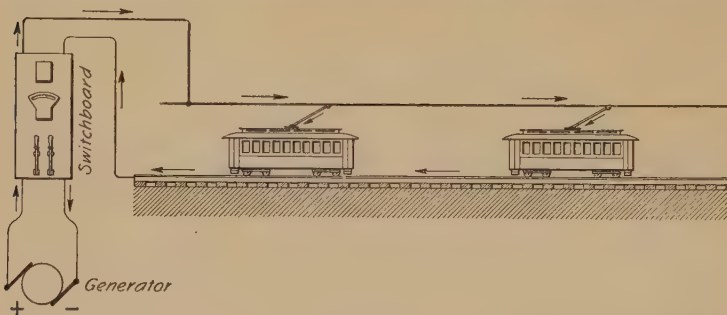


FIG. 1

menting. For instance, on some of the earlier tramways two trolley wires were used, no current being carried by the track rails.

13. Constant-Potential Supply.—All the tramcar circuits in Fig. 1 are electrically in parallel. This is true of all systems of distribution where current is supplied to the cars from a central source. All tramway systems are operated, therefore, at approximately constant potential; that is, constant or nearly constant pressure is maintained between the trolley wire and the track. Wherever a circuit may be formed from the trolley wire to the rail return, through the motors, a current flows and the car is propelled. Each tramcar is independent of all the others on the system, whether they are in motion or not, and each tramcar takes only just as much current as is required to drive it. The arrangement shown in Fig. 1 admits of many modifications. For example, except on very small systems, the trolley wire is not usually large enough to carry the whole current of the system; therefore, *feeders*, or heavy cables, are laid underground from the generating station to the trolley wire at various points. Return cables are sometimes used in combination with the track return.

CONDUIT SYSTEM

14. Principal Features and Construction.—The conduit system is the most expensive method of tramway construction, but it has the advantage of not requiring overhead wires. When the

conduit containing the conductors and the slot opening into it are placed midway between the running rails, the system is

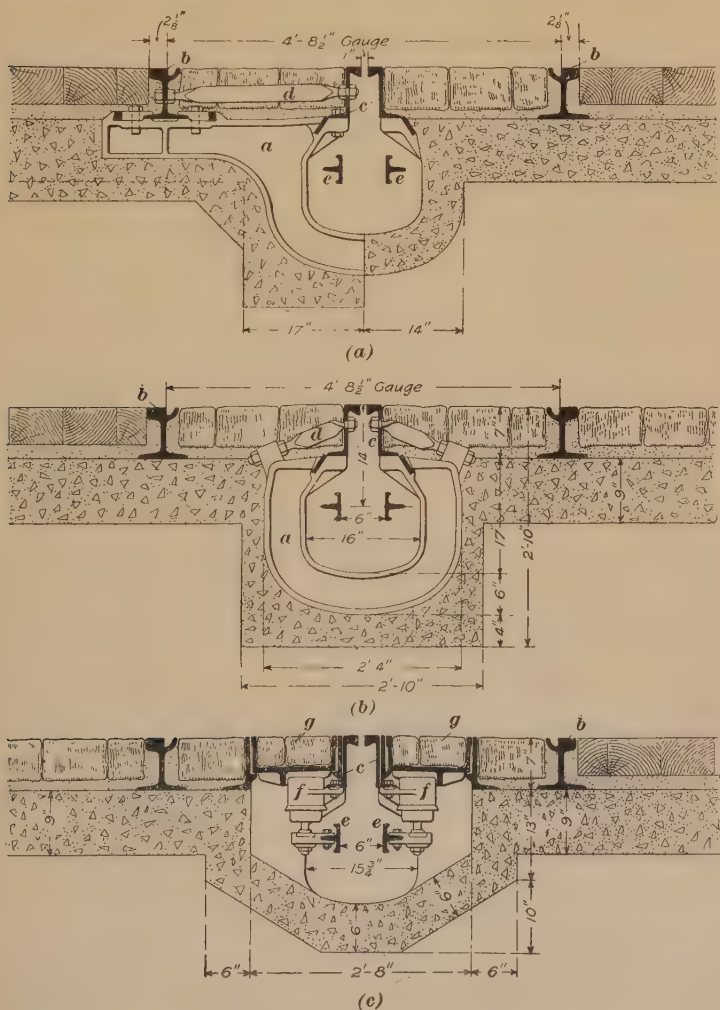


FIG. 2

known as the *central-conduit* or the *centre-slot* system. In the *side-slot* system, one side of the slot opening is formed by one of the running rails.

In Fig. 2 are shown sections of the centre-slot conduit constructed by the London County Council. The shape of the concrete conduit and the width of the slot are maintained by heavy iron yokes *a*, view (b), placed 3 feet 9 inches apart. Every second yoke is extended to support the running rails *b*, as shown

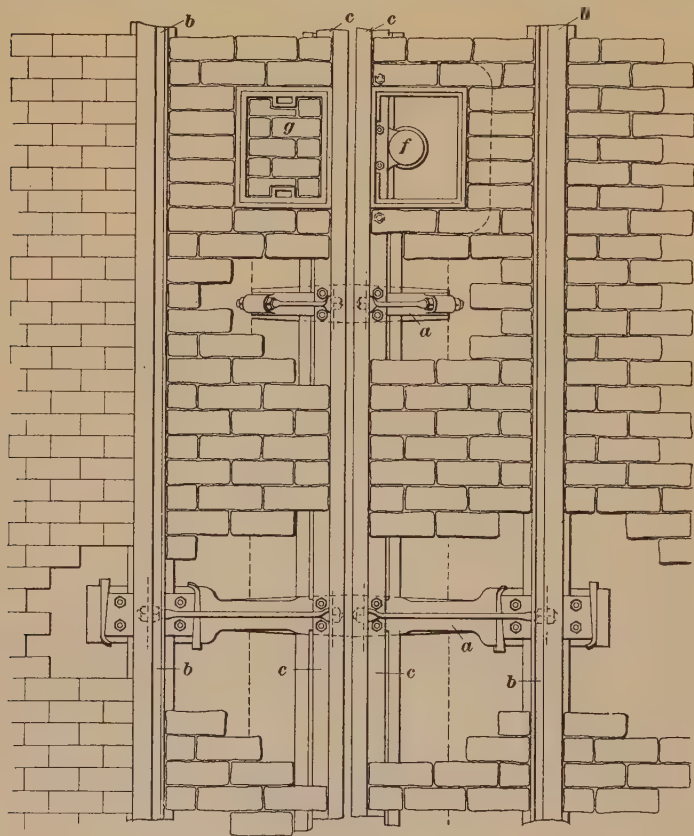


FIG. 3

in (a). The slot rails *c* are bolted to each yoke and are held rigidly in position by the tie-bars *d*. Two steel conductor rails *e*, which are of T cross-section, are supported on insulators *f*, view (c), placed in insulator boxes, which are spaced 15 feet apart. These insulator boxes have removable covers *g*, so as

to provide easy access to the insulators, which are bolted to the slot rails *c*. One conductor rail is positive and the other negative, so that the running rails are not used for carrying current. The conductor rails are divided into $\frac{1}{2}$ -mile sections, which are insulated from one another by means of gaps left between the ends of the conductor rails. The conduit is made sufficiently deep so that mud and water entering the open slot will not reach the conductor rails, and at regular intervals drain connections are provided. The plan of a short length of track is shown in Fig. 3, in which the long and short yokes, the rails, etc., are given the same letters as in Fig. 2.

15. Collection of Current.—The current is collected by means of a *plough* carried by the car and which passes down through the slot to the conductor rails. Two cast-iron shoes, carried by the plough, press against the conductor rails, and cables lead from the shoes to the motors on the car. Fig. 4 shows the arrangement of a simple plough in relation to the conductor rails. Each contact shoe, as *a*, is pressed against the conductor rail *b* by a flat spring *c*. Cables *d, d* are connected through internal slots to the shoes; the cables lead to the motors and controlling devices on the car. The conductor rails *b, b* are supplied with current from the power station by outgoing and return feeders

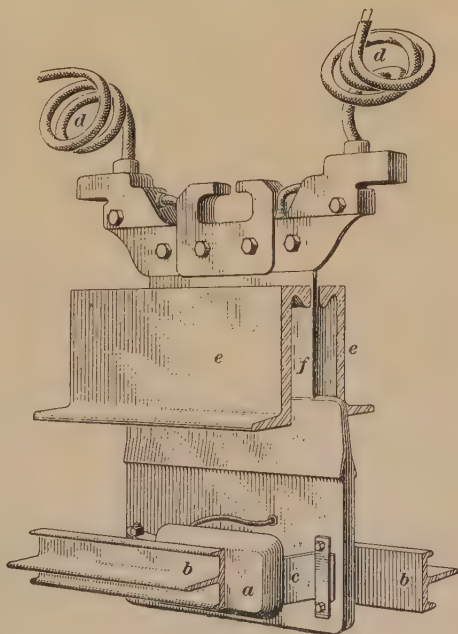


FIG. 4

The conductor rails *b, b* are supplied with current from the power station by outgoing and return feeders

run in ducts in the roadway by the side of the track. The narrow part f of the plough that is suspended between the slot rails e , e is made of steel, and renewable tempered-steel wearing plates are sometimes fastened at the points where the greatest wear occurs.

16. Disadvantages of Conduit System.—The conduit system works satisfactorily if the conduit is sufficiently strongly constructed and kept properly cleaned. Since there is very little clearance for the plough, however, in the slot and between the conductor rails, any breakdown that may occur, due to the plough fouling at points or crossings, entails much greater expense and time in clearing than could occur with the use of overhead conductors. The cost of construction is about twice that of an overhead trolley line, and it is only on lines having a heavy traffic that it can be made to pay. As the construction of the conduit in towns usually necessitates the removal or rearrangement of water and gas pipes, sewers, electric conduits, etc., that may lie in the path of the conduit, and which would not require removal in constructing the overhead system, the difference in capital cost of the two systems is still further increased.

SURFACE-CONTACT SYSTEMS

17. General Features.—In order to avoid both the overhead construction and the expense of building continuous and deep open-slot conduits, several surface-contact or stud systems have been devised. In these systems, *contact boxes*, or studs, placed at regular intervals between the running rails, are made alive by the passage of the car. This is usually done by strongly magnetizing a collecting skate carried on the car and by fitting a magnetic switch in each stud. After the car has passed the stud, the magnetic switch opens and the stud is left dead. The length of the skate and the distance between the studs are so arranged that the skate is always in contact with at least one stud.

In all surface-contact systems, special attention must be paid to the paving; the studs must not be so large, nor project so

far, as to endanger the general traffic of the road, and yet the skate must make good contact with each stud and not interfere with the intervening paving. In the *G.B. surface-contact system* a special collector is used, which, to get over the paving difficulty, is made up of links; these are attracted to the studs in order to make contact and rise clear of them as soon as the studs are passed.

18. The objectionable features of surface-contact collection are the possibility of danger from live studs and the necessity of carrying heavy magnets on the cars, though in some systems the magnets are replaced by a striking bar on the car running in a slot or shallow channel in the road. The danger of live studs is being met by placing trailing attachments on the cars; these either short-circuit the faulty stud and cut off the current, or else indicate in the car when a live stud is left behind the car. When first installed, considerable trouble was caused by the car magnets picking up pieces of iron, which at crossings short-circuited the studs to the rails; this trouble is now avoided by insulating the running rails at these points.

19. **Lorain Surface-Contact System.**—The Lorain surface-contact system is in successful operation in Wolverhampton, and the danger from shock on account of the stud switches failing to work is not serious. A switch, which consists of two contacts, is placed directly beneath each contact stud or plate. The upper or fixed switch contact is connected to the stud head, and the lower or movable contact is in connection with the working conductor through a flexible copper ribbon. The lower contact is mounted on a thin iron plate, and a series of magnets suspended under the car, with their poles near the surface of the ground, attract this iron plate and draw up the lower contact against the upper one, thus establishing connection between the contact plate and the feeder. The contact studs and switches are placed 10 feet apart, and the magnets under the car are 16 feet long. Thus, one switch is always closed and the circuit through a second switch is always completed before the car leaves the first; the circuit is therefore not broken when a switch opens. The collecting skate is more than long enough

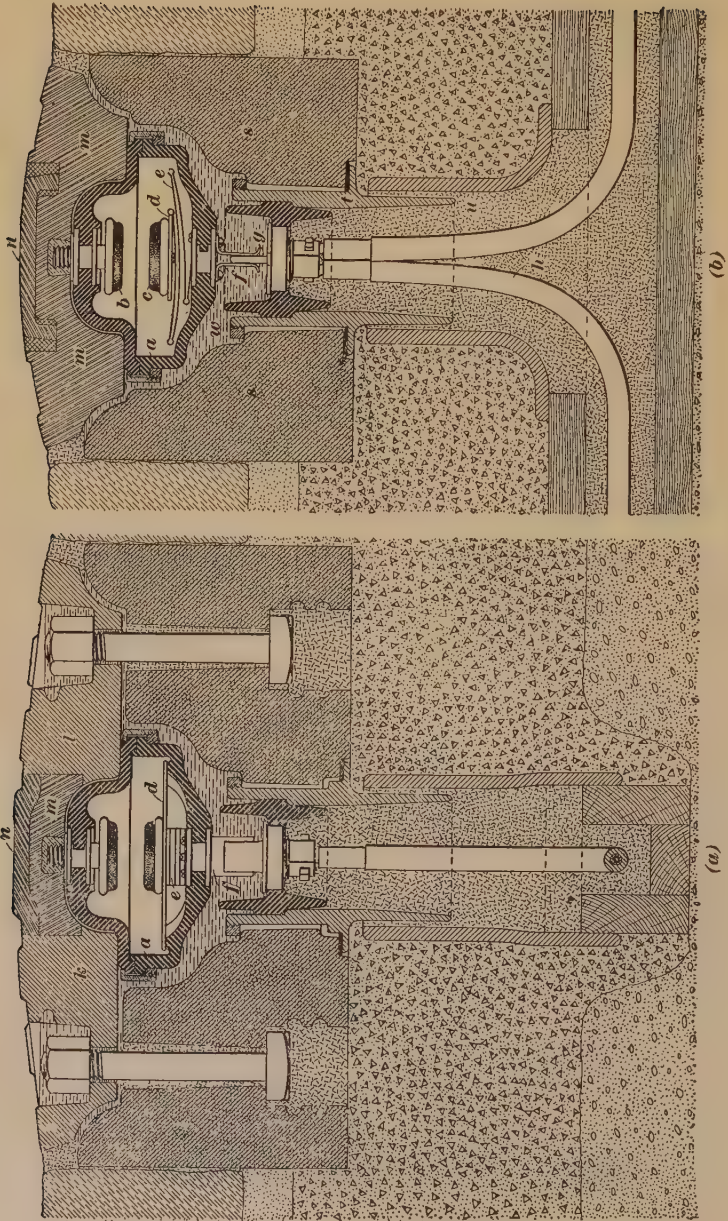


FIG. 5

to extend over two contacts, and there is thus a continuous collection of current. As soon as the magnets have passed over a switch, it again opens, leaving the stud dead after the car has passed. By making the switch contacts of carbon, there is very little danger of their sticking. A small storage battery is provided on the car to furnish current for energizing the magnets when the car is first started or to start the car after the current has been temporarily cut off from the line.

20. Lorain Stud Switches.—Transverse and longitudinal sections of the contact switches of the Lorain surface-contact system are shown in Fig. 5 (*a*) and (*b*); in Fig. 6 are shown the relative positions of the stud switch and the magnets on the car. The switch contacts, which are contained in a water-tight vulca-beston case *a*, Fig. 5, take the form of carbon discs, one, *b*, of which is fixed and the other, *c*, movable. The movable contact *c* is attached to an iron plate or armature *d* that is $4\frac{3}{4}$ inches long, 2 inches wide, and $\frac{1}{16}$ inch thick, and is electrically connected to the spring clips *f* through a folded copper strip *e*. The latter serves both as a flexible connection and also as a guide for the armature when it is drawn upwards by the magnets on the car. The feeder cable is brought up from a conduit below the track to the fixed switch tongue *g*, so that when the case *a* is in place, the movable contact *c* is in direct connection with the feeder *h*.

21. The cover of the switch box consists of four parts *k*, *l*, *m*, and *n*, Fig. 5; *k* and *l* are of cast iron and *m* and *n* of hard manganese steel, which is practically non-magnetic. The top-most section of the cover *n* takes the wear of the collecting skate and is renewable, being held in place by lead run in round it. The switch contact case is fastened to plate *m*, so that by removing the cover the whole case can be lifted out and disconnected from the live feeder. The cover as a whole is bolted to a strong block *s s* of *reconstructed granite*, that is, a block composed of cement and finely broken granite. The feeder cable passes into the switch box through a cast-iron sleeve *t* that fits into a **Y** casting *u*; both of these *t*, *u* are filled with insulating compound. The space *w* surrounding the switch contacts *f*, *g* is

filled with a heavy insulating oil that prevents moisture from accumulating and thus minimizes surface leakage.

22. Working of Lorain System.—The operation of the stud switch will be understood from Fig. 6, where *M* represents one of the magnets carried on the tramcar; the parts of the switch are lettered to correspond with Fig. 5. Six magnets altogether are suspended under each car, the end magnets being the full length of the skate, or 16 feet, apart. As the pieces of manganese steel *m*, *n* between the side blocks *k*, *l* are practically non-magnetic, when a magnet is over a switch, as in Fig. 6, the lines

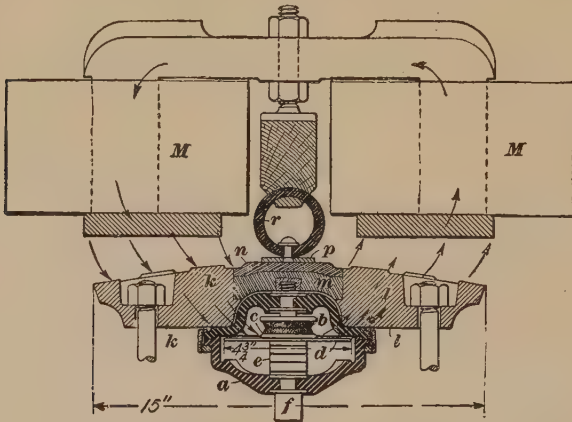


FIG. 6

of force take the path indicated by the arrows and pass through the light armature *d*, drawing it upwards, and thus bringing the carbon contacts together. As soon as the magnets have passed away from the stud, the armature *d* drops, and since the contacts are of carbon there is very little danger of their sticking. The collecting skate consists of a flat steel or copper strip *p* bent up at each end and fastened to a piece of heavy rubber hose *r*, which provides pressure between the skate and the studs. The skate is long enough to bridge across two contact studs, thus providing a continuous collection of current. The magnets are compound-wound. When the car is at rest, the shunt winding

is excited either from the line or from the storage battery carried on the car, and keeps the contact switches closed, so that the car can be started; the series winding provides excitation in case the supply voltage falls too low for the shunt winding to operate the switches; it also holds the switches more firmly in contact as the current taken by the car increases.

23. Dolter Surface-Contact System.—In Hastings, Torquay, and Mexborough the **Dolter surface-contact system** is in use. The Dolter stud switch box *a*, Fig. 7, is fitted with a manganese-steel cover-plate *b*, which carries two magnetic-steel pole pieces *c*.

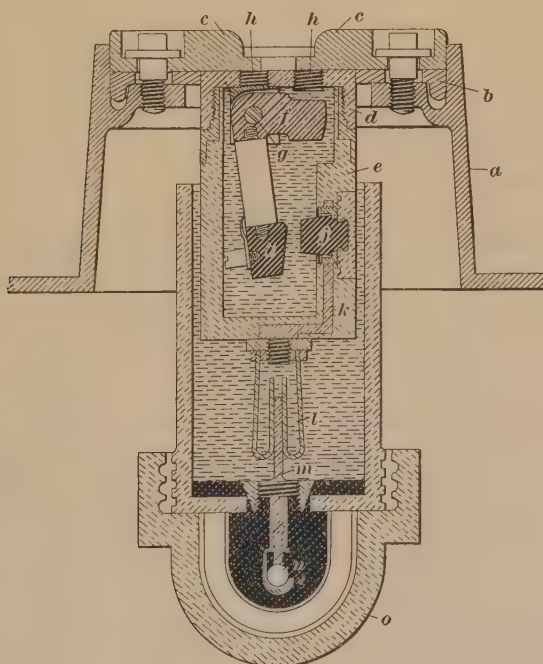


FIG. 7

These pole pieces form part of the magnetic circuit, manganese steel being non-magnetic. Underneath the cover-plate *b* is attached a gunmetal casting *d*, which in turn supports a pot *e*, made of insulating material, and a rocking lever *f* hinged at *g*.

Into the gunmetal casting *d* are fixed two steel plugs *h*, which also form part of the magnetic circuit. Carried by the lever *f* is a carbon contact piece *i*, which, when the upper end of the lever is drawn magnetically toward the plugs *h*, makes contact with a fixed carbon block *j* on the side of the pot. The contact *j* is electrically connected, by means of the strip *k*, to the spring clips *l*, which fit over a tongue *m* coupled to the feeder cable *n*. The latter is laid in an earthenware trough *o*, which is then filled in with bitumen. In order to prevent water from reaching the contacts *l*, *m*, the box surrounding them is filled with heavy oil.

24. Working of Dolter System.—The studs in the Dolter system are operated by a magnet attached to the car, as in the Lorain system. As the magnet passes over each stud, the lever *f*, Fig. 7, is attracted upwards, the carbon blocks *i* and *j* make contact, and the current passes from the cable *n* to the stud and then through the collecting skate to the controllers and motors. The studs are placed about 9 feet apart and the skate is always in contact with one of them; when the car has passed the stud, the lever *f* falls back by gravity to the off-position. As a safeguard against leaving live studs behind the car, a brush attached to the car framework makes contact with the stud after the magnet has passed it; if the stud is alive, a fuse in the stud circuit is blown and the current is cut off.

25. The skate collector, carried on the car in the Dolter system, consists of two long parallel bars hung low enough just to touch the studs. The skate bars are magnetized with opposite polarity by three electromagnets placed between them. As the position of the bars is immediately over the pole pieces *c*, Fig. 7, the magnetic circuit is completed from the bars through the pole pieces *c*, the studs *h*, and the top portion of the rocking lever *f*. The magnets are normally energized by current from the working conductor; should the current be cut off the cable for any reason, the switch levers will fall to the off-position, so that a small storage battery must be carried on the car to energize the magnets and pick the switch levers up again. When they are picked up, the main current is again available for energizing the magnets.

26. G.B. Surface-Contact System.—One of the cheapest surface-contact systems to install is that known as the **G.B. surface-contact system**, so called from the initials of its inventors. It is in use in Lincoln. The conductor is a $1\frac{3}{8}$ -inch steel cable placed in a glazed earthenware pipe, about 5 inches in diameter, which is laid underneath the track. This conductor practically takes the place of the trolley wire in the overhead system, and is supplied with current from the generating station in a similar manner. Immediately over the conductor, and at intervals of from 6 to 9 feet, are placed the studs, which are constructed so that, when a magnet carried on the car passes over them, a small floating armature is forced against the conductor and by making circuit with the cable the stud is energized.

27. Stud of the G.B. System.—Transverse and longitudinal sections through the stud of the G.B. system are shown in

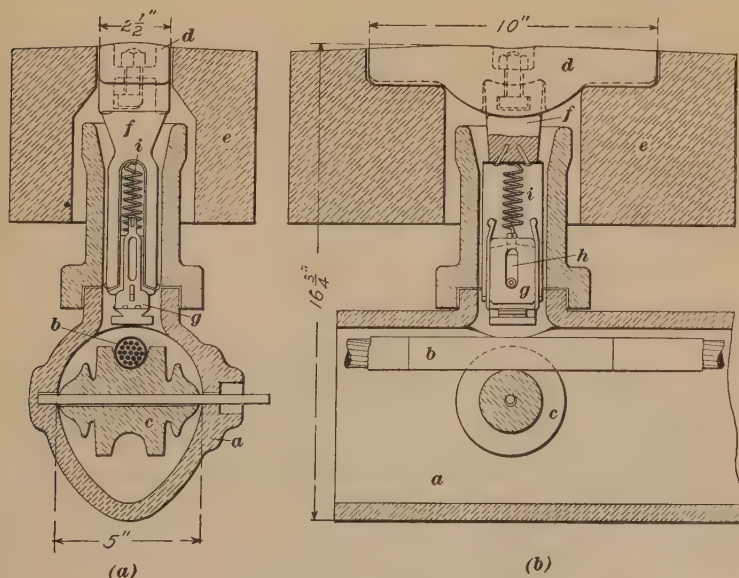


FIG. 8

Fig. 8 (a) and (b). The earthenware pipe *a* protects the conductor *b*, which is supported on the earthenware insulator *c*. Projecting downwards from a cast-iron stud head *d* set in a

granite block *e* is a brass-lined cast-iron fork *f*. A galvanized-iron floating armature *g* works within this fork ; its movement is limited by small pins that work in the slot *h*. The armature *g* carries a carbon contact-block held in a copper clip, and is normally kept from making contact with the conductor by a light spiral spring *i*. Flexible copper leads connect the copper clip with the main portion of the stud. When the car magnet passes over the stud, the lines of force pass through the stud and the forked projection to the steel conductor. The small floating armature sets itself against the pull of the spring *i*, so as to bridge the gap between the fork and the steel cable, and energizes the stud through the flexible copper connections. In order to prevent any injury to the strands of the working conductor through arcing at the switches, short sleeves of galvanized steel are slipped over the conductor throughout its whole length.

28. Working of the G.B. System. — The car equipment of the G.B. system consists, as usual, of a means of collecting the current and a magnet for operating the studs. The magnet is fixed rigidly to the car body and is connected to a storage battery carried on the car. The collector consists of a number of iron links suspended from a wire rope which takes the place of the usual rigid skate ; when a stud is magnetized, these links are attracted and bear on the stud, thus conveying the current

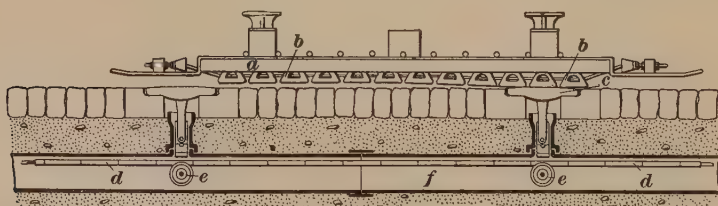


FIG. 9

to the car. When clear of the stud the links are drawn up out of the way of the paving. This arrangement allows the studs to be placed nearly flush with the roadway. In Fig. 9 is shown a longitudinal section of the collector. A rigid bar *a* running the whole length of the collector forms the magnet poles. It also

supports the iron links *b*, which are attracted toward the stud *c*; *d* is the working conductor, *e* the supporting insulator, and *f* the earthenware pipe enclosing the conductor.

29. Robrow Surface-Contact System.—A system in use on the Continent and in India, and which differs from those just de-

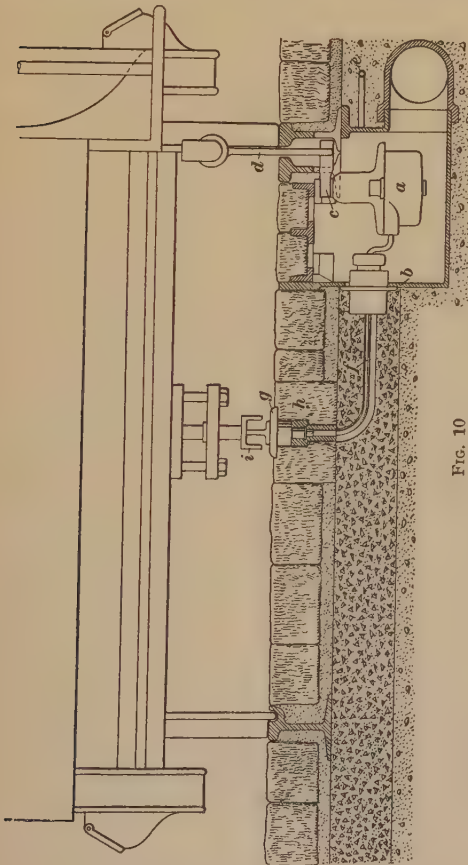


FIG. 10

scribed, is the **Robrow surface - contact system**; in it, the switches controlling the supply of current to the studs are operated mechanically. In Fig. 10 is shown a section through the track at a stud and switch box. The contacts of a water-tight switch *a*, which is enclosed in a cast-iron box *b*, are closed by a lever *c* that is operated by a bar *d* fixed to the car. When the car has passed, the lever springs back and the switch returns to its normal open position. The current passes from the feeder *e*, through the switch and a short cable *f* to the stud *g*, which is set in a granite block *h*. The car equipment consists

of a skate *i*, fixed in the centre of the car and long enough to make contact with two studs at the same time. The operating bar *d*, which keeps the stud switch closed while the car is passing over it, is a little longer than the skate and is attached to the

side of the car truck. The advantages of this system are that the switches can be substantially made, as they are operated mechanically, and also there is no heavy magnetic gear to carry on the car. Against these advantages must be set the cost of the double rail forming the slot in the road and the consequent labour of keeping the slot clean, and also the disadvantage of having a long operating bar attached to the truck.

STORAGE-BATTERY SYSTEM

30. Limitations of Use of Storage Batteries.—Many attempts have been made to work electric tramcars by means of storage batteries carried on the cars, but none of them have proved successful. The constant vibration of the cars soon causes the cells to deteriorate, while the acid fumes given off are both offensive and destructive. For some special kinds of traction work, batteries have proved desirable, as, for example, the operation of electric shunting locomotives for use on manufacturing works or electric generating stations.

Batteries may often be used to great advantage, however, on tramway systems when they are placed in power houses or substations to take up fluctuations in the load or even to carry the whole load for short intervals. In work of this character, where the battery is stationary, the deterioration is not nearly so rapid as when the cells are subjected to vibration and shocks on a car. Moreover, a stationary battery can be made heavy enough to secure durability, whereas a tramcar battery must be made as light in weight as possible, at the expense of durability. Even when the batteries carried on a tramcar are made as light as possible, the storage and driving equipment of the car become extremely heavy compared with the corresponding weight for most of the other systems of driving, either electrical or mechanical.

THIRD-RAIL SYSTEM

31. Contact Rail and Shoe.—In the third-rail system, current is conveyed to the moving cars by a third rail mounted on insulators at one side of the track and slightly above the level

of the running rails. Current is collected by the car by means of shoes that slide on the contact rail; the return path of the

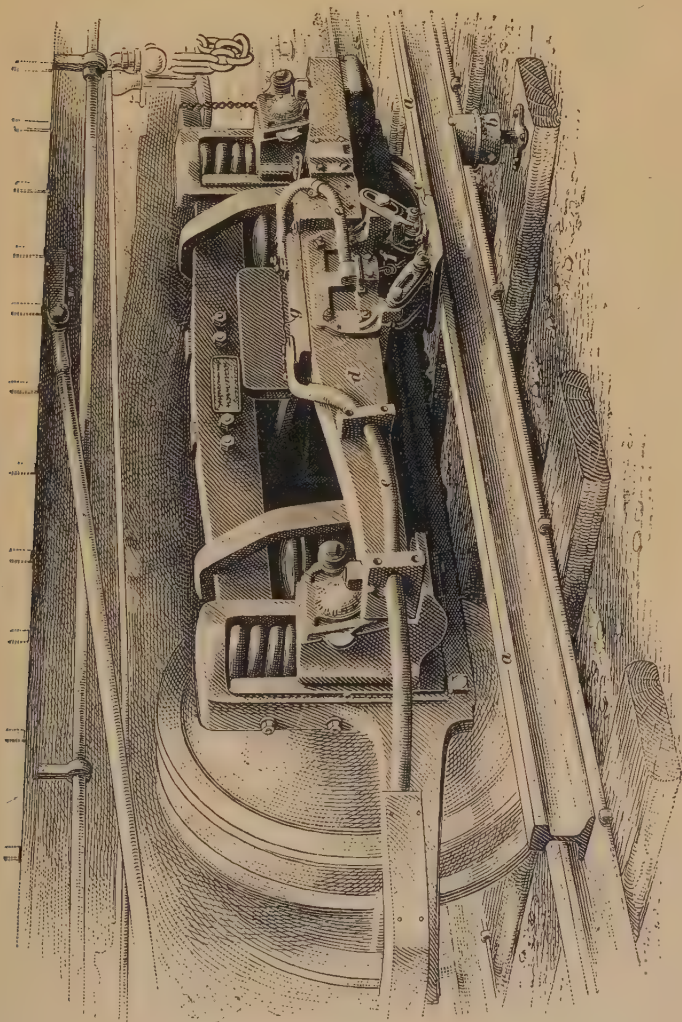


FIG. 11

current is through the track rails, as in the overhead system. In Fig. 11 is shown the arrangement of the contact or collecting shoe on a typical third-rail line. The third rail *a* is of girder

section, and is supported on insulators *b* resting on every fifth sleeper, which is extended for this purpose. The cast-iron collecting shoe *c* is suspended from links, so that it is free to move up and down through a limited range, in order to follow any inequalities in the surface of the third rail, and the whole collecting device is attached to a wooden beam *d* carried by the truck. Cable *e* leads to the controllers and motors on the car, and electrical connection is maintained with the shoe by means of the bare flexible copper cable *f*. The mechanical links are not depended on to carry the current. In some cases, a copper fuse is placed at *g* to cut off the current in case of short circuit.

TRANSMISSION AND DISTRIBUTION OF CURRENT

DIRECT- VERSUS ALTERNATING-CURRENT TRANSMISSION

32. Simple Direct - Current Transmission. — The simplest method of distributing current to the tramway tracks is by direct current transmitted from the generators without the use of any intervening transforming or converting devices. The distance beyond which it becomes uneconomical to transmit current at 500 volts for traction purposes depends on the load to be dealt with. The Board of Trade limit the load which may be carried by any one feeder to 300 kilowatts, which is equivalent to 600 amperes at 500 volts. Moreover, the drop in the return rails must not exceed 7 volts, and the current density in the rails must not be more than 9 amperes to the square inch; in the case of two 95-pound rails forming a single track the maximum current on this basis would be about 170 amperes. When the drop of 7 volts in the rail return is likely to be exceeded, negative boosters must be used for the return current; and when the drop in the positive feeder will be excessive, positive boosters also must be used.

33. Alternating - Current Transmission. — For transmission beyond a certain distance, it is usually more economical to

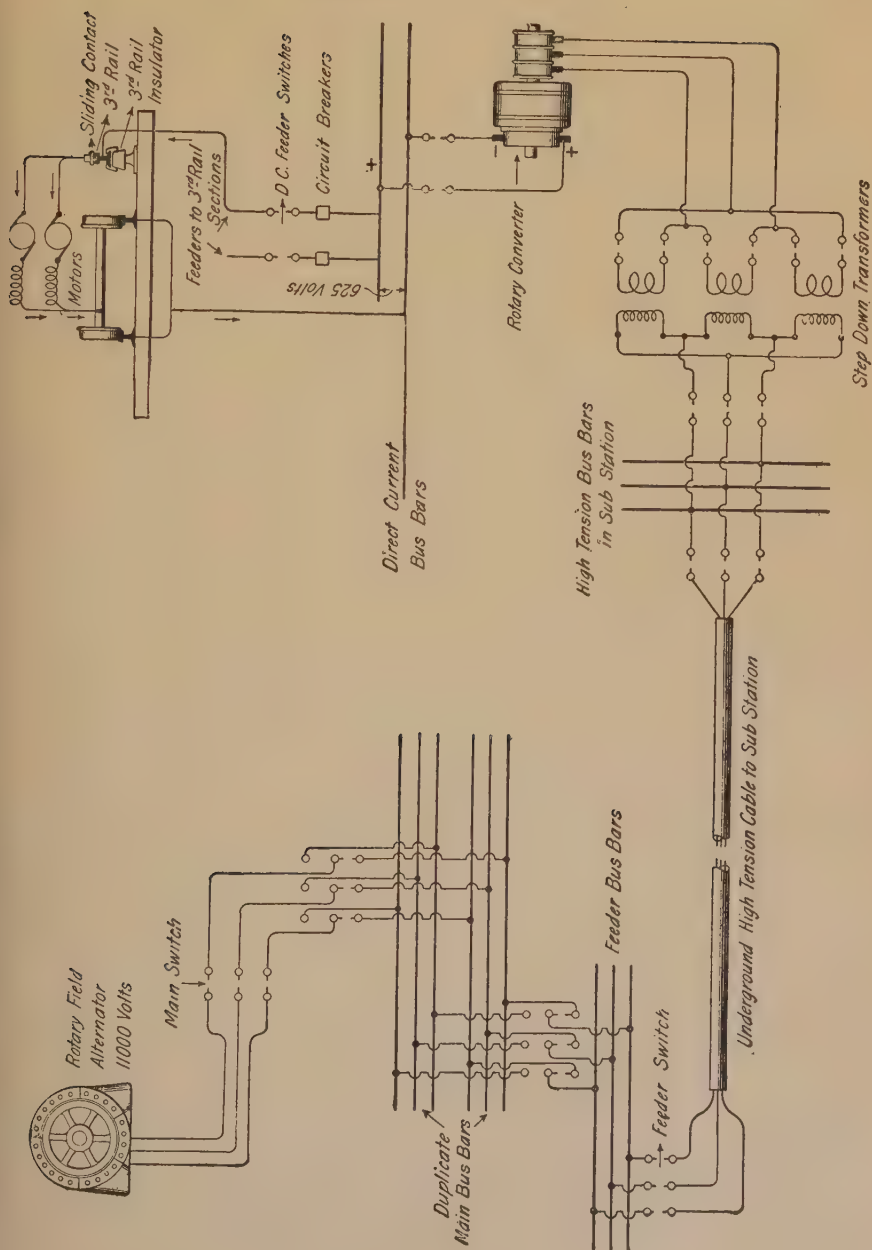


FIG. 12

generate at high pressure and transmit to a substation. In such a case, the high-tension transmission is usually carried out by three-phase alternating current, at a voltage probably between 5,000 and 6,500 volts. The high-tension current is conveyed from the power station to the substation through three-core cables laid underground. At the substation, the current is transformed to low-tension alternating current, which is then converted to direct current at 550 volts by means of rotary converters. Alternatively, motor generators may be used, in which case the static transformers are unnecessary, and the full alternating-current voltage is applied to the motor which drives the direct-current generator. Rotary converters are used on the Glasgow tramways, the London United tramways, and the London Underground railways, while motor generators are used on the London County Council and on the South Lancashire tramways.

34. Diagram of Extra-High-Tension Transmission System.—In Fig. 12 is shown a diagram of an extra-high-tension transmission system, using transformers and rotary converters in the distant substation, similar to those used by the London Underground railways. The current is generated in a central station by revolving-field three-phase alternators direct-connected to 8,000-horsepower engines. The use of the revolving-field type of machine is necessary to enable the current to be generated at 11,000 volts in the machine, and so to save any transformation at the generating station. The current is distributed by means of heavily insulated lead-covered cables, laid underground in conduits, to a number of substations, and is there transformed to low voltage. Rotary converters in the substations convert the alternating current to direct current at about 625 volts, and from the substations it is supplied to the cars by means of a third rail laid along the ordinary track. The third rail would be replaced, in the case of most tramway systems, by an overhead trolley wire, or the working conductor of the conduit or surface-contact systems.

35. Choice of System.—The question as to the exact load point at which it is advisable to install boosters for direct-current

transmission over moderate distances, and when to adopt high-tension transmission, must be considered for each particular case. The capital cost of each system must be estimated, and the annual capital charges must be compared with the cost of the energy lost in transmission. The more economical method is that in which the annual cost of the wasted energy equals the annual interest on the capital expended, plus an allowance for depreciation. With a simple 500-volt direct-current distribution, the cost of the energy lost may be calculated from a knowledge of the load to be dealt with and the resistance of the conductors, positive and negative. When boosters are used additions must be made to the losses, equal to the losses in the boosters themselves, while both the amount and the rate of depreciation must be increased owing to the increased capital cost and the introduction of moving machinery. Where high-tension transmission is adopted, there must be considered the cost of the losses in the high-tension line, in the transformers, rotary converters, and the low-tension system.

ESTIMATE OF POWER REQUIRED

36. Tractive Effort and Tractive Resistance.—The propelling effort exerted by the car motors to keep a car in motion, and applied by the wheel tires on the head of the rail, is called the **tractive effort** and is usually expressed in pounds pull. To maintain motion, this effort must be equal to the sum of the forces which oppose the motion. The frictional and wind resistances which oppose uniform motion on the level are collectively known as the **tractive resistance**. This resistance depends on the condition of the rails, the efficiency of the car mechanism, and the resistance of the wind. The wind resistance is variable, but the other two factors are constant enough, at ordinary tramcar speeds, for one to choose an average force, such as 20 pounds, per ton of weight necessary to maintain motion.

Let f = tractive resistance, on level track, in pounds per ton ;

W_t = weight of tramcar, in tons ;

F = total tractive effort, or pull, required on the level.

Then,

$$F = f W_t$$

For instance, assuming $f = 20$, a force of 20 pounds will maintain the uniform motion of a car weighing 1 ton. If the car weighs 10 tons, the tractive effort required will be $F = 20 \times 10 = 200$ pounds.

37. Power Required to Maintain Motion.—To calculate the work performed by a force while moving a body through a certain distance:

Let F = force applied to body, in pounds ;

s = distance through which body is moved, in feet ;

W = work done, in foot-pounds.

Then, $W = F s$ (1)

For example, if a force of 10 pounds is exerted to move a body through a distance of 10 feet, the work done will be $10 \times 10 = 100$ foot-pounds. If 33,000 foot-pounds of work is performed in 1 minute, the power exerted is 1 horsepower.

Let F = total force, in pounds ;

S = speed, in miles per hour.

Then, since the speed, in feet per minute, is $\frac{5,280 S}{60}$, the work

done per minute is $\frac{5,280 S F}{60}$, and

$$\text{H.P.} = \frac{\text{foot-pounds per minute}}{33,000} = \frac{5,280 S F}{60 \times 33,000}$$

$$\text{or,} \quad \text{H.P.} = \frac{S F}{375} \quad (2)$$

EXAMPLE.—(a) Find the horsepower required to propel a car, weighing 10 tons, and moving at the rate of 10 miles an hour on the level, if the force necessary to keep the car in motion, neglecting wind resistance, is 200 pounds. (b) Find the current taken by the motor at 500 volts.

SOLUTION.—(a) The distance the car will move in 1 min. is $\frac{10 \times 5,280}{60} = 880$ ft., so that the amount of work performed in 1 min. is $200 \times 880 = 176,000$ ft.-lb., which equals

$$\frac{176,000}{33,000} = 5.33 \text{ H.P.} \quad \text{Ans.}$$

Or, applying formula 2,

$$\text{H.P.} = \frac{10 \times 200}{375} = 5.33$$

(b) As there are 746 watts in 1 H.P., and the line pressure is 500 volts, the current required, neglecting losses in the motors and control gear, is

$$\frac{746 \times 5.33}{500} = 8 \text{ amperes, nearly. Ans.}$$

38. Effect of an Incline.—The steepness of an incline may be expressed as the ratio of the vertical rise in travelling a certain distance to the distance travelled. Or, if ab , Fig. 13, represents

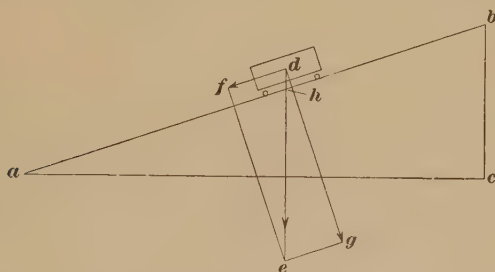


FIG. 13

the gradient and ac is a horizontal line, the steepness of the gradient may be expressed by the ratio $\frac{bc}{ba}$. In addition to the

force necessary to maintain motion on the level, to move a car up an incline there must be expended sufficient force to overcome the tendency of the car to run down the gradient. The weight of a car ascending the gradient may be represented by the line de acting vertically through the centre of gravity of the car. The weight may be resolved into the two forces df and dg , which are at right angles to each other. The force df is parallel to the gradient ab and represents the force that tends to make the car run down the hill. The force dg represents the reaction of the rail.

As the line df is parallel to the line ab , the angle fde is equal to the angle ahc ; and as the line de is parallel to the line bc , the angle ahc is equal to the angle abc . Therefore, the angle fde is equal to the angle abc . As the angles efd and acb are right angles, the triangles edf and abc are similar, and $\frac{df}{de} = \frac{bc}{ba}$, from which, $df = de \times \frac{bc}{ba}$. That is, the force tending to send

the car backwards down the hill is proportional to the weight of the car and to the steepness of the gradient.

39. Propelling Force Required on Rising Gradient.—The force that is required to move a car uniformly up a gradient is greater than that required to maintain motion on the level by an amount which depends on the gradient.

Let W_t = weight of car, in tons ;

G = gradient expressed as ratio of rise to length of incline, both in feet ;

F_w = force required to balance weight of car, in pounds.

Then, $F_w = 2,240 W_t G$ (1)

Let F_g = total tractive effort required to propel car up incline, in pounds ;

F = total force required to overcome resistance on level ;

f = tractive resistance per ton on level track, in pounds.

If the other quantities have the same values as in formula 1, then the total force required to move a car up a gradient is

$$F_g = F_w + F = 2,240 W_t G + f W_t \quad (2)$$

40. Tractive Effort on Incline.—The steepness of a gradient is usually expressed by the distance which must be travelled along the gradient, in feet, in order to rise an amount equivalent to a vertical distance of 1 foot. Thus, a gradient of 1 in 100 means that there is a rise of 1 foot in travelling along the gradient a distance of 100 feet. From formula 1, Art. 39, it follows that the force required per ton of the weight of the car on such a gradient is $\frac{2,240 \times 1 \times 1}{100} = 22.4$ pounds. To this amount,

in order to obtain the total propelling force required to maintain motion, must be added the amount of the tractive resistance on the level. If the tractive resistance f is 20 pounds per ton, the total tractive effort required on the gradient is $F_g = 22.4 + 20 = 42.4$ pounds per ton.

41. The steepness of a gradient may be expressed as a percentage. Thus, if an incline is said to have a gradient of 3 per cent., it is meant that for every 100 feet travelled along the

incline the track rises 3 feet. The percentage rise is sometimes referred to the horizontal distance travelled, but it is more general to refer all measurements to the distance measured along the incline. For all gradients usually met with in practice, it makes very little difference, so far as numerical results are concerned, which is taken, because the distance travelled along the incline is practically the same as the horizontal distance.

Thus, on a 1 per cent. gradient, the car rises 1 foot for every 100 feet travelled. The extra work done, due to the gradient, in propelling a car along it for a given distance is thus equivalent to lifting the weight of the car through one-hundredth of the distance travelled. Otherwise, for each ton that the car weighs, each 1 per cent. of the rise of the gradient has the same effect as the addition of $\frac{2240}{100} = 22.4$ pounds to the tractive effort required on the level.

Let f_g = tractive effort, on incline, in pounds per ton ;

f = tractive resistance, on level, in pounds per ton ;

G_1 = percentage of gradient.

Then, $f_g = f + 22.4 G_1$

EXAMPLE 1.—What is the horsepower required to move a car weighing 10 tons up a gradient of 1 in 30 at the rate of 10 miles an hour, if the tractive effort is 20 pounds per ton on the level ?

SOLUTION.—Substituting in formula 2, Art. 39,

$$F_g = 2,240 \times 10 \times \frac{1}{30} + 20 \times 10 = 947 \text{ lb., nearly}$$

Substituting in formula 2, Art. 37, the power required is

$$\frac{10 \times 947}{375} = 25 \text{ H.P., approximately. Ans.}$$

EXAMPLE 2.—If a tractive effort of 20 pounds per ton is required to maintain the uniform motion of a 10-ton car on a level track, what effort, per ton, will be required on a 5 per cent. grade ?

SOLUTION.—For each 1 per cent. of gradient, the force must be increased by 22.4 lb. per ton over the amount required on the level ; hence, applying the formula,

$$f_g = 20 + 22.4 \times 5 = 132 \text{ lb. per ton. Ans.}$$

ACCELERATION

42. **Starting From Rest.**—In the calculations that have been made so far, it has been assumed that the motion of the cars was uniform. It requires, however, much more power to start a car

and to get it running at full speed than to keep it in motion after it has been started. If the output of the motors were based merely on calculations relating to uniform motion, the motors would be too small to start the car rapidly from rest. In the early days of electric traction, the motors provided on the cars were too small, largely because the great increase of power required at starting had not been allowed for.

43. Power Required in Speeding Up.—In order to start a tram-car from rest and bring it up to speed, a certain amount of energy must be expended over and above that necessary to overcome the frictional or tractive resistance. The additional energy so expended is stored in the moving car as kinetic energy. The amount of kinetic energy which is stored in speeding up the car depends on the weight of the car and on the final speed. The power to be exerted during the starting period will depend, in addition, on the length of time allowed to attain full speed. In tramway problems, the rate at which the speed of a car is increased (*acceleration*) or decreased (*retardation*) may be expressed in feet per second per second, or in miles per hour per second. For example, if the acceleration is $1\frac{1}{4}$ miles per hour per second, in each second the speed of the car is increased by $1\frac{1}{4}$ miles per hour. If the car starts from rest, at the end of the first second it will be moving at the rate of $1\frac{1}{4}$ miles per hour, at the end of the second second, at $2\frac{1}{2}$ miles per hour, and so on.

44. Speed and Power Curves.—In Fig. 14 are shown typical speed and power curves for an electric train with an equipment capable of producing rapid acceleration. These are applicable also to the case of an electric tramcar, but while the curves for the latter will be similar in form and principle, the quantities will be smaller. Curve *A* shows the relation between speed and time. The letters *M.P.H.*, found at the left side of the diagram, mean *miles per hour* and refer to the numbers below. Curve *B* shows the total current supplied, and curve *C* the voltage. Starting from a standstill, the speed increases at an almost uniform rate up to 25 miles per hour; the curve then bends over and the rate of increase in speed, namely, the **acceleration**, becomes less until at $37\frac{1}{2}$ miles per hour the curve has become

nearly horizontal; the speed is then nearly uniform and the acceleration has become practically zero. After 93 seconds, the current is shut off and the train coasts along, by virtue of the energy stored in it, but with gradually decreasing speed. The brakes are applied at the latter end of the run and the train is retarded and finally brought to a stop, as indicated by the straight sloping line at the right of the figure.

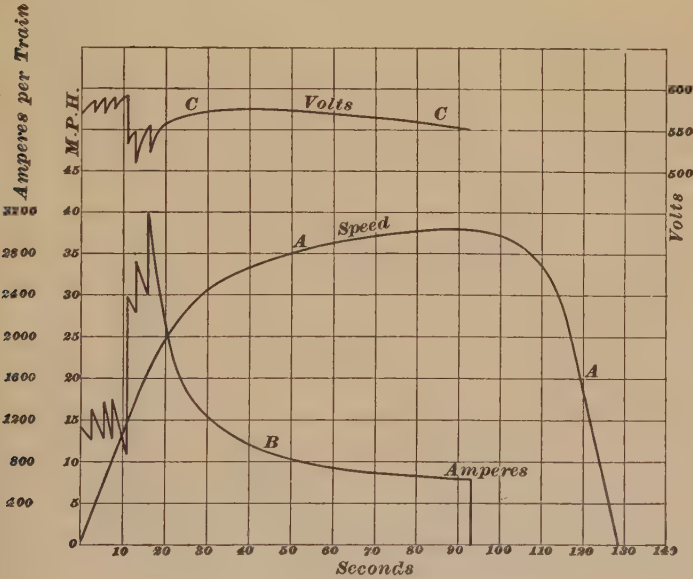


FIG. 14

45. When the train is started with all the starting resistance in series with the motors, the total current is about 1,100 amperes. As the resistance is cut out, the current varies, as shown by the notches in the curve, during the first 10 seconds; the motors are then thrown in parallel and the total current rises to nearly 2,400 amperes, after which it further increases to 3,200 amperes, as the resistance on the parallel notches is cut out. Up to this point the current in each motor has remained approximately constant and the tractive effort has, therefore, been nearly constant. The tractive resistance is also approximately constant for moderate speeds, with the result that the speed is almost

uniformly accelerated from 0 to 25 miles per hour during the first 20 seconds. The average acceleration during this interval is thus $1\frac{1}{4}$ miles per hour per second. As the speed increases beyond 25 miles per hour, the current rapidly diminishes and the tractive effort also diminishes. The acceleration therefore decreases, and when the current has dropped to about 650 amperes the speed has become nearly uniform. The tractive effort is then wholly utilized in overcoming the train resistance; during the acceleration period a large part of the total effort was used in increasing the speed and thereby storing energy in the train, and the remainder went to overcome the train resistance.

46. Force Required to Produce Acceleration.—The force F_a required, in addition to that necessary to overcome the tractive resistance and forces due to inclines, in order to make a car increase its rate of speed, is easily calculated.

Let m = mass of car ;
 a = acceleration.

Then, $F_a = m a$ (1)

But m equals the weight w of the car divided by the acceleration g due to gravity ; hence,

$$F_a = \frac{w}{g} a \quad (2)$$

If w is expressed in pounds, g in feet per second per second, and a in feet per second per second, F_a will be the force, in pounds, and $F_a = \frac{w}{32.2} a$, since g is equal to 32.2 feet per second per second. Usually, in traction calculations, the weight of the train or car is expressed in tons instead of pounds, and the acceleration in miles per hour per second instead of feet per second per second. One mile per hour = 1.467 feet per second and 1 ton = 2,240 pounds. If, then, A is the acceleration in miles per hour per second, the number of feet per second per second will be 1.467 A ; and if W_t is the weight of the car, in tons, the number of pounds will be 2,240 W_t . The equation will then

become
$$F_a = \frac{2,240 W_t}{32.2} \times 1.467 A$$

or,
$$F_a = 102 W_t A \quad (3)$$

EXAMPLE.—If an electric car weighs 10 tons, what accelerating force must be exerted to bring the car from a standstill up to a speed of 12 miles an hour in 15 seconds, assuming the acceleration to be uniform during this period?

SOLUTION.—The acceleration A is $\frac{12}{15} = .8$ mi. per hr. per sec. W
 $= 10$ tons; hence, from formula 3,
 $F_a = 102 \times 10 \times .8 = 816$ lb. Ans.

47. Total Driving Force During Acceleration.—From formula 3, Art. 46, the tractive effort necessary to produce an accel-

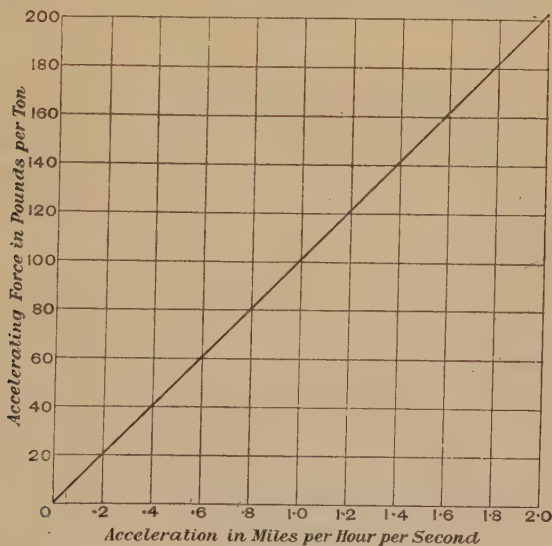


FIG. 15

eration of 1 mile per hour per second is 102 pounds for each ton weight of car. The relation between the acceleration, in miles per hour per second, and the accelerating force necessary to produce it, in pounds per ton, is shown in Fig. 15. It must be remembered that this accelerating force is additional to the force required to overcome the train resistance. Again, whenever a train is started, two kinds of inertia must be overcome; that is, kinetic energy is stored in two ways. The train must be made to move horizontally, the force required for this acceleration being given by formula 3, Art. 46, and a certain amount of

energy is required to overcome the inertia of, or to be stored as kinetic energy in, the rotating parts, such as armatures, wheels, gears, and axles; this may amount to 8 or 10 per cent. additional to the force given by the formula. Therefore, taking the rotational inertia into account, formula 3, Art. 46, should be written

$$F_a = 110 W_t A$$

Thus, if the force required to overcome the tractive resistance is taken as 20 pounds per ton, for moderate speeds on a good track, and if the force required to produce both rotational and linear acceleration is 110 pounds per ton for an acceleration of 1 mile per hour per second, the total tractive effort required to speed up the car at this rate will be 130 pounds per ton.

48. Limit of Adhesion.—The maximum tractive effort that can be applied at the rail surface is limited by the slipping of the wheels on the track; therefore, the possible acceleration that can be imparted to a car cannot exceed a certain maximum amount. There is also a certain maximum steepness of the incline that a car can ascend. The steepness of this incline must be such that the **adhesion** or the maximum tractive effort which can be exerted by the motors without wheel slippage is equal to the force tending to send the car backwards down the hill. The adhesion between the wheels and the rails depends on the total weight on the driving wheels and on the coefficient of friction between the wheels and track. The latter varies greatly with the condition of the rails, and also with the kind of car wheels. It is considerably less for wheels with chilled-iron tires than for those with steel tires. As a safe outside figure, the adhesive force may be taken as about 15 per cent. of the weight on the driving wheels. Thus, the maximum tractive effort that can be exerted without causing the wheels to skid may be taken as $2,240 \times .15 = 336$ pounds per ton of weight on the driving wheels.

49. It should be noted particularly that the weight referred to is only that portion of the total weight which is carried on the driving wheels. In the case of a single-truck car having two motors, all the wheels are driving wheels and the whole weight therefore rests on them; hence, this style of car is well adapted

for hill climbing and running on slippery tracks. If the cars are built with double trucks and two motors, the weight resting on the driving wheels will not be more than 55 to 70 per cent. of the total weight, thus limiting the maximum tractive effort to some figure between 185 and 235 pounds per ton of weight of car. If the cars have double trucks with four motors, one on each axle, the whole of the weight is supported on the driving wheels; hence, four-motor equipments are desirable for tramways in hilly localities using double-truck cars. For most lines with moderate gradients, however, two-motor equipments usually give sufficient adhesion.

50. Steepest Incline on Which Car Will Start.—If the adhesion and the tractive resistance of any car are known, the steepest gradient on which the car will start may be ascertained by calculation.

Let f' = tractive force, in pounds per ton of weight of car, necessary to start car on level;

G = gradient expressed as 1 divided by length of incline for 1 foot rise;

W_t = weight of car, in tons;

b = ratio of adhesive force to weight on driving wheels, expressed as a decimal;

c = ratio of weight on driving wheels to total weight, expressed as a decimal.

Then the actual weight on the driving wheels, in pounds, is $2,240\ c\ W_t$; the total adhesive force is $2,240\ c\ W_t\ b$; the total force required for starting on an incline of which the gradient is G is $2,240\ W_t\ G + f'\ W_t$. If the tractive effort and the adhesive force are equal, then $2,240\ c\ W_t\ b = 2,240\ W_t\ G + f'\ W_t$, and $G = \frac{2,240\ c\ W_t\ b - f'\ W_t}{2,240\ W_t} = c\ b - .00045\ f'$

About 70 pounds per ton is a fair value for the tractive effort f' required to start a car on the level under ordinary conditions; if, however, the acceleration required is very great, the effort required during the time that the car is gaining speed may be much higher than this. The greatest acceleration obtainable will be limited by the wheels skidding.

EXAMPLE.—If 65 per cent. of the weight of a car is supported on the driving wheels and if the adhesive force is 15 per cent. of the weight on the driving wheels, what is the maximum grade on which the car can start without the wheels skidding, assuming that it requires an effort of 70 pounds per ton of weight of car to start on the level ?

SOLUTION.—In this case, $c = .65$, $b = .15$, and $f' = 70$. Then, from the formula,

$$G = .65 \times .15 - .00045 \times 70 = .0975 - .0315 = .066, \text{ or } \frac{1}{15}, \text{ nearly}$$

That is, the wheels will skid if the gradient exceeds 1 in 15. Ans.

POWER CONSUMPTION

51. **Size of Units in Power Station or Substation.**—In order to determine the size of the power station or substation units, it is necessary to know the maximum number of cars it is possible or desirable to run and the average current which each car will take. The number of the cars depends on the frequency of the service, the length of the line, and the average speed ; the average current of each car depends on the type of car and the topography of the road as regards its gradients and the number of curves. The frequency of the service on any route requires a close preliminary study of the district to be served, and a subsequent adjustment to suit all the varying conditions which soon make themselves apparent after the opening of the line. The units installed in the power station or substation should be sufficient to meet the traffic at the busiest hours with a safe margin of spare plant in case of breakdown. For dealing with special occasions, such as holidays, occurring only two or three times a year, all the plant should be utilized, as it is not economical to provide spare plant for the sake of 3 or 4 days in the year. Tramway motors in the British Isles are usually between 25 and 35 horsepower, two motors being generally fitted to each car. The exceptions to this standard arrangement are in some small systems, where only one motor may be fitted, and also where double-truck cars are operated in hilly districts ; in this case, four-motor equipments are sometimes used.

52. **Speed of Cars.**—The average speed of the cars will usually be from 6 to 8 miles an hour, depending on the amount of traffic carried and the busyness of the thoroughfares through which the

line passes. Before any line is open to the public, a Board of Trade inspection is made, with the object of fixing the maximum permissible speeds to be allowed on the different portions of the route, and to make regulations for compulsory stops at dangerous points. At curves and crossings, the speed may probably be limited to about 4 miles an hour, while in wide streets and with cars fitted with powerful magnetic brakes a maximum speed up to 16 miles an hour may be allowed. Still higher speeds may be allowed over private rights-of-way.

53. Average Current Per Car.—The average current taken from a 500-volt trolley wire by a tramcar under ordinary conditions may roughly be taken as 1·5 amperes per ton of weight, including passengers. A single-truck car weighs from 8 to 10 tons and a double-truck car from 11 to 15 tons. The weight of passengers may be allowed for at the rate of a ton for 15, so that a single-truck car carrying 50 passengers will probably weigh from 11 to 13 tons, and a double-truck car with 70 passengers from 16 to 20 tons. The average current required for a single-truck car will therefore be from 17 to 20 amperes, and for a double-truck car from 24 to 30 amperes. These figures will be found approximately correct for tramway systems where the rolling stock and track are in fairly good condition and the gradients and curves are not abnormal. Where specially heavy gradients must be climbed, due allowance would have to be made. Where long and steep inclines occur, the question of regenerative control, by which energy is returned to the trolley wire from cars descending the hills, is worthy of careful consideration.

54. For example, suppose that a tramway system which is 10 miles long is so situated that it may be economically supplied from one centre. A 5-minute service is to be arranged, the average speed of the cars being 8 miles per hour and the average current consumption per car being 20 amperes. The distance apart of the cars, that is, the distance run by any one car in 5 minutes, will be $8 \times \frac{5}{60} = \frac{2}{3}$ mile. The total number of cars on both up and down tracks will therefore be $\frac{2 \times 10}{\frac{2}{3}} = 30$ cars.

TABLE I
PARTICULARS OF ELECTRIC TRAMWAY EQUIPMENTS

Num- ber of Sys- tem	Length of Route Miles	Length of Track Miles	Popula- tion Served	Track		Gauge		Maxi- mum Gra- dient in in	Speed of Cars		Num- ber of Cars	Power Station	
				Feet	Inches	Type of Engine	Total Output Kilo- watts	Num- ber of Genera- ting Sets	Type of Engine	Total Output Kilo- watts	Num- ber of Cars	Type of Engine	Total Output Kilo- watts
1	7.25	13.25	83,000	4	0	16	7	8	Vertical high-speed	400	36	Vertical high-speed	400
2	5.5	9.0	91,000	3	6	17	12	12	Vertical high-speed	550	22	Vertical high-speed	550
3	14.95	25.3	110,000	3	6	9	5½	16	Three horizontal tandem slow-speed	675	45	Three horizontal tandem slow-speed	675
4	13.52	23.53	119,700	4	8½	13.5	7	14	One vertical high-speed	1,625	50	One vertical high-speed	1,625
5	10.5	17.2	120,000	4	8½	16	8	12	Vertical high-speed	600	30	Vertical high-speed	600
6	28	35.5	120,000	4	7¾	11	7	12	Horizontal slow-speed	2,200	70	Horizontal slow-speed	2,200
7	17	28.34	162,000	4	7¾	9.7	8	14	Vertical slow-speed	1,150	53	Vertical slow-speed	1,150
8	5	9.5	165,500	4	8½	16.5	10	15	Three horizontal slow-speed	500	14	Three horizontal slow-speed	500
9	14.5	28.5	211,500	4	7¾	17	6	14	One vertical high-speed	2,075	100	One vertical high-speed	2,075
10	20	37	240,200	4	8½	18	7½	16	Four vertical slow-speed	2,500	140	Four vertical slow-speed	2,500
11	16.25	26.88	275,600	4	8½	20	12	12	Vertical slow-speed	1,560	116	Vertical slow-speed	1,560
12	54.25	92.5	300,000	5	3	12	8	8	Vertical high-speed	5,000	331	Vertical high-speed	5,000
13	40.7	74.7	463,200	4	8½	9.5	6¾	16	One steam turbine	4,440	279	One steam turbine	4,440
14	51.2	96.6	477,100	4	8½	18	7.3	16	Three horizontal slow-speed	6,150	270	Three horizontal slow-speed	6,150
15	95	189.5	1,050,000	4	7¾	11.9	7½	11½	One vertical high-speed	10,000	776	One vertical high-speed	10,000

The total average current will be $30 \times 20 = 600$ amperes. If the station voltage is 550, the total demand on the station under normal conditions will be $600 \times 550 = 330,000$ watts = 330 kilowatts. A satisfactory arrangement of the power station to supply such an output is to install three generating units of 200-kilowatts capacity each, making a total of 600 kilowatts installed. Under normal conditions, this will provide one spare unit, all three units being operated on specially busy days; the arrangement will also allow one 200-kilowatt unit to run during the quiet periods of the day, two units being run under normally busy conditions. If two units of 350 kilowatts each are installed, 50 per cent. of the whole plant will be provided as spare instead of only $33\frac{1}{3}$ per cent. as when divided into three units; moreover, a larger unit than necessary will have to run during the period of light load. Economy both of capital and running expenses is thus gained by dividing up the plant into three units instead of into two units only.

55. Equipment of Typical Tramways.—Certain particulars of the track, cars, and power stations of a number of British tramway systems are given in Table I. The reference number of the system, length of route, the equivalent length of single track, and the population served are given in the first four columns; the tramways are arranged in the order of the populations served. The gauge and maximum gradient of the tracks are given in the succeeding columns, these are followed by the average speed attained by the cars and the maximum speed permitted by the Board of Trade, and the number of cars in use on the system. The number of the generating sets installed at the power station, their total output, and the type of engine driving the generators are then given. Vertical high-speed engines are largely used for the smaller sizes of generating sets, while for the larger units steam turbines are in some cases installed instead of large, slow-speed reciprocating engines.

56. Costs.—The generating works costs obtained on the different tramway systems in Great Britain vary from .35d. to 1d. per kilowatt-hour; where current is purchased, the price paid varies from 1d. to 2d. per unit. Table II gives the power

consumption and cost of power for the electric-tramway systems that were described in Table I. The number of passengers carried on each system during 1 year is shown. The energy consumption of the cars, in units per car-mile, has been calculated from the number of car-miles run and the number of units used during the year. The works costs, in fractions of a penny per unit generated, are made up of the costs for fuel; labour; oil, water, and stores; and maintenance and repairs. The works costs do not include any management expenses or capital expenses for interest on capital or depreciation of plant; these must be added to the works costs to obtain the total power costs.

57. Combined Lighting and Traction Generating Stations.

The question of combining lighting and traction stations for economical working is one which has been greatly discussed; it is now generally admitted that, where possible, the lighting and traction loads should be controlled from one station. The advantages are more apparent in small stations than in large, but even in Glasgow, where a 10,000-kilowatt station was put down to supply the tramway system, it has been found advantageous to link it with the lighting stations, in order to interchange power during times of heavy load and so keep the capital and operating costs of both systems as low as possible.

SITUATION OF POWER HOUSE

58. Supply of Coal and Water.—When a power station is erected solely for traction purposes, the conditions which govern its situation are the facilities for obtaining coal and water and the necessity of keeping the station as near as possible to the position of most economical distribution; that is, generally, as near as possible to the centre of the load. Due regard must be paid to the cost of land and also to the class of neighbourhood; if erected in a residential locality the land will be more expensive and the supply authority are liable to actions at law for the nuisances caused by smoke and noise. The banks of canals and rivers are the most satisfactory positions, as the coal can be

brought up in barges and a supply of cold water for condensing is always at hand. The large power station for the Glasgow tramways is erected on the banks of a canal, while the stations for the London County Council tramways and for the London electric railways are on the banks of the Thames. Where such a site for the power station is not available, ponds must be made, and the condensing water from them must be used over and over again. Cooling towers and fans for cooling the water must also be installed and maintained at considerable cost. The questions of condensing and the provision of an adequate supply of cold water for this purpose are two of the most important considerations in modern power stations fitted with steam turbines, as the best possible vacuum is necessary to run these machines at a high efficiency.

59. Determination of Centre of Load.—The generating station should be placed as near as possible to the centre of the system which it will supply. By this is meant the centre of the load or traffic. Since underground cables must generally be used to convey the power from the generating station to the various sections of the tramway route, a part of the power generated will be lost in them. If the cables are not of sufficient size, they will cause a loss of voltage that will make itself very strongly felt in its effect on the speed of the cars and also on the amount of heat developed in the motors. The loss of power in transmission in each feeder depends on the resistance of the line and the amount of current that it must carry. Hence, even if all the feeders are of equal length, the losses in them may vary. The centre of the load may not be the geographical centre of the system; in fact, these two centres may seldom fall in the same place. The true load centre may be found by calculation in the same way as the centre of gravity of any system of heavy bodies. The geographical centre depends on the number of miles of track and how these are disposed; the load centre depends on how the load is distributed.

60. In Fig. 16 *AB* represents 10 miles of track that is free from gradients and sharp curves and on which a certain number of cars 1, 2, 3, 4, etc., of about the same weight and equipped

with motors of the same size, run at regular intervals. The geographical centre, or centre of mileage, is in this case at a point P midway between the two ends, so that there is 5 miles of the route on each side of it. In this case, the load centre also is at P ; for, suppose that all the cars, except the two on the extreme ends, are running at full speed. Since the track is level and the cars and motors are alike, they will all take about the same power; and since the loads are evenly distributed throughout the length of track, the centre of gravity of the system will fall on the centre line cl . So, also, if all the cars, except the two end ones, are supposed to stand still or to coast along with the power off and the two end ones start at the same time, there

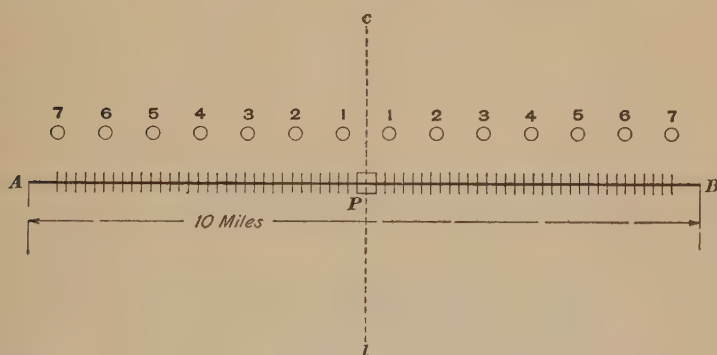


FIG. 16

will be similar loads at both ends of the line and the point P will still be the centre of load; this, therefore, is the point where the power house should be placed.

61. It is not implied that the load, even on such a simple layout, will always be as evenly distributed as in the ideal case just described, for such a condition will be the exception rather than the rule. Suppose that A , Fig. 16, is in the outskirts of a large city, the centre of which is at B ; then, in the morning and evening, when people are going to and returning from work, the load leans toward the city end of the line at B , but during the rest of the day it is uniformly distributed. Again, suppose that from the middle of the line to B is uphill. The motors of

those cars that are ascending the hill will be called on to do more work than those travelling on the level toward *A*, so that the ideal site for the station will be shifted toward *B*. In this case, the mileage centre remains the same as before, but the load centre is changed.

62. Influence of Future Extensions.—In fixing the site for the power station, future extensions and the probable increase in traffic incidental to the development of outlying districts should be borne in mind and the site selected accordingly. Suppose, for example, that the full line *AB*, Fig. 17, represents 5 miles



FIG. 17

of track put down at the first building of a given tramway, and that, in accordance with the demand existing at that time, the power station was put at *P*, the centre of load for *AB*, which is supposed to be level track. Suppose, however, that the tramway has been extended at a later date to a point *C*, so that now $AB = AC$. When the district through which *AC* runs becomes built up, the load density will be quite as great on the new part of the route as on the old, in which case, assuming the load to be distributed fairly evenly throughout the distance *BC*, the proper place for the power house would now be at the point *P'*, midway between *B* and *C*. So long as *AB* constituted the whole road, the power house situated at *P* was at the centre of an evenly distributed load, and the same loss of power would attend the transmission of a given amount of power to one end of the line as to the other. With the opening of the extension to *AC*, however, the power house at *P* is only $2\frac{1}{2}$ miles from one end *B* and the distance *PC*, or $7\frac{1}{2}$ miles, from the other end *C*.

63. With the arrangement just described, the total transmission losses to all parts of the system are greater, in any case, than if the power station were at *P'*, Fig. 17. Moreover, should

a large number of the cars, through trouble of some sort, be held up near the far end *C* of the line, the voltage drop in transmission, due to the great distance and to the large current taken in trying to start all the cars at once, will seriously delay the cars in getting up to time again. If the station were put at *A* in the first place, it would be at one end of the line as long as *AB* was the whole road, and, for the time being, would not be at the centre of load; but if the construction of the extension *AC* were only a matter of time, it would be far better to put the station at *A* in the first place, notwithstanding the extra line loss at first, due to want of balance on the shorter line, with a view of obtaining the best results when the extension is put into operation.

64. Large Tramway System.—If a tramway system is much larger than that just considered, certain other factors make it desirable to place the power station away from the centre of the

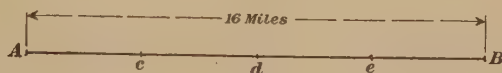


FIG. 18

load. These are due to the fact that the limiting distance for economical direct-current distribution is usually about 4 miles from the power station or substation. If the greater part of a given tramway system is included within this limit, only one distributing centre will be necessary, and the most economical position for it will be at the centre of the load. If the system extends along one line, perhaps 12 to 16 miles long, the most economical method of supply will possibly be with the addition of one substation; the power station will then be placed away from the load centre. For example, if *AB*, Fig. 18, is a route 16 miles long, on which *c*, *d*, *e* are points at 4-mile intervals, the best position of the power station will be near *e*, and the corresponding position of the substation will be near *c*. This will give each distributing centre a 4-mile radius to deal with. Due regard must be paid to the radius of economical direct-current distribution, and the substations and power station must be disposed of accordingly.

65. Alternating - Current Transmission and Direct - Current Distribution.—In the instance just given, the power station must generate both direct and alternating current, direct current for supplying the cars in the power-station radius and alternating current for transmitting to the substation. If some of the generators are constructed for alternating current and some for direct, at least one spare unit of each type must be provided. If the circumstances are such that it is desirable to avoid this, any one of the following arrangements are available: All the generating units may be constructed for alternating current, and the current for local distribution obtained from rotary converters and transformers placed in the power station; or direct-current generators may be installed and alternating current obtained by means of rotaries and transformers or motor generators. A third method is to put down both direct-current generators and alternators in connection with a reversible rotary converter. At times of light load, the rotary may be driven by transformed alternating current; it will then supply direct current for the local area as required; or it may be driven from the direct-current generators, when it will supply alternating current for transmission to the substation.

66. Conditions Affecting Choice of Site.—In deciding the best situation for the generating station, if it were only a matter of finding the probable centre of the load, the problem would be comparatively easy. But in many cases it is made very difficult, on account of several other considerations that enter into the question. A site where every pound of coal to be burnt under the boilers must be hauled to the power house, or where it is difficult to get water for the boilers and the condensers, is, of course, out of the question, even if it is the centre of the load. In many cases, a compromise must be made between conflicting conditions. Load conditions will point to one site, and good cheap water will point to another; but, in every case, the coal bunkers must be situated so that the coal may be conveyed directly into them from a canal barge or lighter, or from coal trucks that can be run alongside of them by means of a railway siding.

EXAMPLES OF SMALL TRAMWAY POWER STATIONS

STEAM-DRIVEN STATION

67. **Power Station.**—As the method of operating large and small tramways is nearly the same, so far as the details of the cars and the line construction are concerned, two typical tramway installations for a small number of cars are here given. The first of these installations is for a steam-driven power station ; the second is equipped with oil engines. The first tramway system has 15 miles of single track laid on a route of 12 miles. There is a fairly easy route, with maximum gradients of 1 in 20 and curves of a minimum radius of 46 feet ; the rail gauge is 4 feet 7 inches. There are twenty-six cars, of the double- and single-deck types, on four-wheeled trucks, each double-deck car being fitted with two 30-horsepower motors.

68. In Fig. 19 (*a*) and (*b*) are shown the power house and car sheds. The engineers' offices and stores occupy the front part of the power station (*a*). Behind these is the engine room. This is equipped with generators wound to give any pressure between 480 and 550 volts, for this station supplies both lighting and power. High-speed engines are direct-coupled to the generators. One set *a* has an output of 600 kilowatts, two *b*, *c* have an output of 175 kilowatts each, and one *d* has an output of 50 kilowatts. Two switchboards are used, one *e* controlling the lighting load and the other *f* controlling the traction circuits. In a large room over the offices, two sets of storage batteries are installed. The lighting battery is divided into two parts of 120 cells each, so as to supply the three-wire system with 480 volts between the outers ; the traction battery contains 240 cells. An automatic reversible booster *g* works in conjunction with the traction battery to equalize the load on the generators. Two balancing booster sets *h*, *i* are used to balance the three-wire system of lighting distribution and to charge the lighting battery. Behind the engine room is the boiler room, which contains four Babcock water-tube boilers placed in two pairs *j*, *k* ; four short steel

chimneys *l* are placed one behind each boiler. The coal bunkers *m* are arranged along the end of the boiler room and the feed-pumps are placed in a small room *n* at one side. The car shed and depot, Fig. 19 (*b*), is at present large enough for nine 28-foot

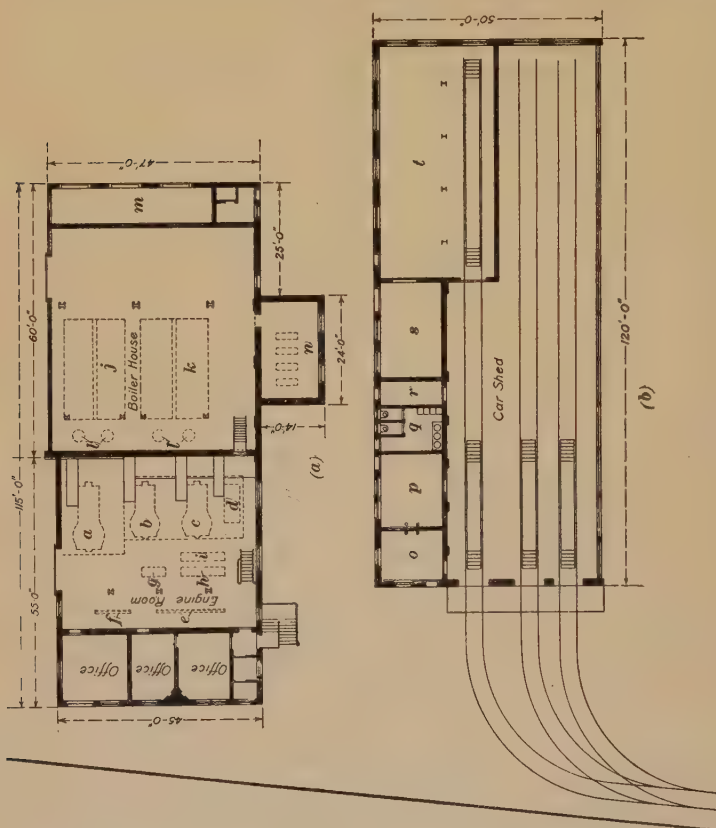


FIG. 19

cars, but may be extended. A ticket and time office *o*, men's room and lavatory *p*, *q*, sand shed *r*, stores *s*, and workshop *t*, occupy one side of the building.

OIL-DRIVEN STATION

69. In Fig. 20 is shown the car depot and plan for an oil-driven generating station. This generating station supplies a tramway which has 2 miles of double track and 8 miles of

single. The gauge is 3 feet 6 inches. The maximum gradients are 1 in 11, the sharpest curves have a 55-foot radius, and the maximum permissible speed is 12 miles an hour. There are thirteen double-deck cars on four-wheeled trucks, each fitted with two 40-horsepower motors, as the line is very hilly.

70. The power station, Fig. 20 (b), is divided into two parts, the engine and battery rooms. The engine room contains two

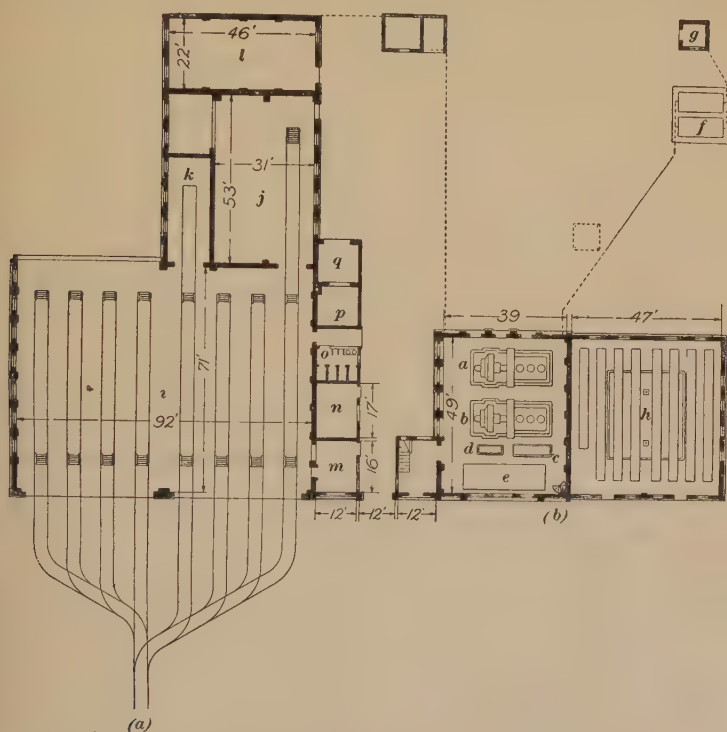


FIG. 20

240-brake-horsepower Diesel engines *a*, *b*, each direct-coupled to one 165-kilowatt direct-current generator. These sets run at a normal speed of 172 revolutions per minute. It also contains a battery booster *c* and a negative booster *d*, which is connected in the return circuit. The load is controlled by a switchboard *e* at one end of the engine room. The crude petroleum oil used

by the engines costs about £3 per ton, and the consumption per kilowatt-hour under normal conditions is guaranteed by the engine builders not to exceed .7 pound. Therefore, taking into consideration that no firemen are employed and that there are no standby charges for keeping up steam in boilers, a plant of this kind will under certain circumstances prove more economical than a steam-driven plant of the same size. The crude oil is stored in oil tanks *f* some distance from the engine room. It is then pumped into smaller tanks in the engine room, as required for use, by means of a small electric pump in the pump house *g* near the oil tanks. The battery room *h* contains 260 cells, and has a capacity of 500 ampere-hours, or an output of about 250 kilowatts for 1 hour.

The car depot, Fig. 20 (*a*), consists of a car shed *i* and repair shop *j*, paint shop *k*, and stores *l*. In addition, there are a ticket office *m*, men's messroom *n*, lavatory *o*, sand dryer *p*, and sand store *q*. The car shed is arranged to hold sixteen cars.

TRAMWAY-STATION RECORDS

TYPICAL DAILY-LOG SHEET

71. Form of Daily Log.—In Fig. 21 is shown the **daily-log sheet**, or form, which is filled each day in a generating station supplying a combined traction and lighting load. It contains the record of the working of the station from 10 p.m. of one day to 10 p.m. of the next, the station being worked in three 8-hour shifts, which change at 6 a.m. and 2 and 10 p.m. The records for each day group themselves in four sections. The first section consists of half-hourly readings of the performance of the generating machinery, the load on the feeders, and data regarding the boilers and condensers. These readings show the variations of load on the station and the behaviour of the machinery throughout the day, and are recorded by the switchboard attendant on duty in each shift. Other sections include a shift report and a summarized statement of the results of the day's working; these are usually entered by the shift engineer in charge of each shift.

Time	AMPERES													BUS-BAR VOLTAGE				Boilers Working				Steam Pressure Pounds Sq. In.
	Generators				Works Light- ing & Power		Motor Generator and Balancer			Lighting Bus-Bars			Rotary Con- verter	Outers		Pilot						
	1	2	3	Total	+	-	A	C	B	+	Neutral	-		+	-	1	2	3	4			
P.M. 10.15	420	T		420	40	65	0		-15	354	+70	302	53	485	235	235		✓	✓	✓	✓	160
10.45	415	T		415	39	63.5	-5		-10	324	+25	308	50	485	235	235		✓	✓	✓	✓	152
11.15	360	T		360	39	63.5	-5		-11	242	+22	227	60	480	234	234		✓	✓	✓	✓	160
11.45	345	T		345	39	63.5	-5		-11	214	+21	205	56	478	232	232		✓	✓	✓	✓	165
A.M. 12.15	320			320	39	63.5	-4.8	T	-16	199	+19	194	55	475	230	230		✓	✓	✓	✓	160
12.45	310			310	39	63.5	-4.5	T	-15	209	+19	192	60	475	230	230		✓	✓	✓	✓	158
1.15	315			315	39	63.5	-4.5	T	-15	191	+17	188	65	475	230	230		✓	✓	✓	✓	160
1.45	315			315	39	63.5	-4.0	T	-15	183	+17	185	70	474	230	230		✓	✓	✓	✓	160
2.15	310			310	39	62	-4.0	T	-13	183	+17	182	50	474	230	230		✓	✓	✓	✓	155
2.45	312			312	39	63	-4.0	T	-12	180	+13	182	55	474	230	230		✓	✓	✓	✓	160
3.15	312			312	39	62	-3.8	T	-12	180	+15	185	55	474	230	230		✓	✓	✓	✓	162
3.45	310			310	39	63	-3.8	T	-15	180	+12	186	60	474	230	230		✓	✓	✓	✓	162
4.15	305			305	39	63	-4.5	T	-20	185	+12	186	50	474	230	230		✓	✓	✓	✓	162
4.45	300			300	39	62	-5.2	T	-25	186	+15	187	50	474	230	230		✓	✓	✓	✓	160
5.15	296	T		296	55	46	-5		-11	190	+16	180	60	474	230	230		✓	✓	✓	✓	155
5.45	300	T		300	55	47	-5		-11	197	+30	176	55	474	230	230		✓	✓	✓	✓	160
6.15	480	T		480	41	74.5	-7		-9	404	+26	360	60	476	231	231		✓	✓	✓	✓	165
6.45	560	T		560	41	74.5	-7		-9	431	+45	405	85	460	231	231		✓	✓	✓	✓	160
7.15	640	T		640	45	83.5	-30		+5	462	+37	451	180	490	230	230		✓	✓	✓	✓	152
7.45	580	T		580	44	75	-5		-10	377	+35	341	190	485	230	230		✓	✓	✓	✓	157
8.15	320	T		320	45	70	0		-15	199	+27	135	100	475	230	230		✓	✓	✓	✓	160
8.45	403	T		400	45	73	+3		-17	227	+32	175	170	475	230	230		✓	✓	✓	✓	150
9.15	430	T		430	40	71	+3		-17	240	+80	184	170	475	230	230		✓	✓	✓	✓	157
9.45	380	T		380	40	67.5	0		-15	207	+43	160	180	475	230	230		✓	✓	✓	✓	160
10.15	380	T		380	41	65.5	-5		-10	207	+32	167	150	475	230	230		✓	✓	✓	✓	163
10.45	400	T		400	41	63	-3		-12	182	+35	153	165	475	230	230		✓	✓	✓	✓	157
11.15	340	T		340	40	64	0		-16	195	+39	152	105	475	230	230		✓	✓	✓	✓	160
11.45	360	T		360	40	61.5	0		-16	182	+30	157	155	475	230	230		✓	✓	✓	✓	160
P.M. 12.15	360	T		360	40	61.5	-10		-5	207	+30	162	150	475	230	230		✓	✓	✓	✓	160
12.45	320	T		320	40	62.5	-5		-10	143	+53	114	140	475	230	230		✓	✓	✓	✓	165
1.15	180	T		180	39	59	-10		-5	69	+30	53	62	475	230	230		✓	✓	✓	✓	155
1.45	180	T		180	39	60	-3		-12	83	+30	53	55	475	230	230		✓	✓	✓	✓	165
2.15	320	T		320	39	63.5	0		-15	161	+32	119	130	475	230	230		✓	✓	✓	✓	160
2.45	320	T		320	40	55	-5		-10	197	+27	158	90	475	230	230		✓	✓	✓	✓	150
3.15	450	T		450	40	64	+30		-40	309	+55	290	130	475	230	230		✓	✓	✓	✓	157
3.45	460	T		460	41	75.5	+25		-30	330	+70	300	55	483	230	230		✓	✓	✓	✓	167
4.15	700	T		700	44	80	0		-10	552	+31	481	125	487	230	230		✓	✓	✓	✓	163
4.45	800	T		800	45	87	+5		-10	665	+106	582	95	495	230	230		✓	✓	✓	✓	167
5.15	770	T		770	45	82	0		-10	700	+75	625	40	485	230	230		✓	✓	✓	✓	167
5.45	785	T		785	45	79.5	+10		-20	670	+86	592	65	495	230	230		✓	✓	✓	✓	165
6.15	615	T		615	43	74	+15		-23	547	+80	444	53	490	236	236		✓	✓	✓	✓	169
6.45	623	T		623	46	71	+13		-21	549	+77	482	60	490	236	236		✓	✓	✓	✓	160
7.15	630	T		630	39.5	50	-5		0	548	-3	500	63	490	236	236		✓	✓	✓	✓	157
7.45	625	T		625	59	63	-10		-5	528	0	502	55	490	236	236		✓	✓	✓	✓	155
8.15	596	T		596	58	60	-10		-13	495	0	455	55	490	236	236		✓	✓	✓	✓	157
8.45	595	T		595	41	82	-7		-10	490	+17	432	63	487	236	236		✓	✓	✓	✓	160
9.15	590	T		590	62	67	-10		-3	500	+1	432	43	490	236	236		✓	✓	✓	✓	163
9.45	550	T		550	60	59	-10		-7	455	+3	410	60	490	236	236		✓	✓	✓	✓	160

BOARD OF TRADE TEST

(1) Current between Earth Plates

8

amperes.

(4) Leas

(2) Maximum Current Observed from Earth Plates

—

amperes.

(3) Maximum Voltage between Negative Bus-Bar and Rail Return

4

volts.

NOTE.—The Board of Trade Test No. 4 is to be made only when the line

LOG

CONDENSER					SHIFT REPORT		
Temperature		Temperatures, F.			Shift	Remarks	
Vacuum	O.W. Inlet	O.W. Outlet	A.P. Discharge				
2	Inches						
167	24.0	80	86	110	Night. 10 p.m. to 6 a.m.	Motor generator dynamo C put on traction load and N° 2 generator taken off. 11:55 p.m. — N° 1 traction-feeder circuit breaker out and in at 11:20 p.m. — N° 1 out & traction-feeder switches out at 12:0 midnight, and in again at 4:0 a.m. — N° 4 generator put on traction load and dynamo C taken off at 4:55 a.m.	
160	24.0	80	86	110			
165	24.8	78	80	98			
170	25.0	78	75	95			
175	25.8	76	72	90			
180	26.0	74	72	84	Day. 6 a.m. to 2 p.m.	N° 2 traction-feeder circuit breaker out and in at 7:30 a.m.	
150	26.3	74	70	80			
148	26.5	70	70	75			
142	26.5	68	68	75			
140	26.5	65	68	72			
145	26.5	62	68	70	Evening. 2 p.m. to 10 p.m.		
140	26.5	60	67	70			
150	26.6	60	68	70			
160	26.6	60	67	70			
158	24.8	60	70	76			
150	24.0	60	78	78			
145	22.5	68	80	90			
140	22.0	70	80	120			
145	20.8	75	86	120	UNITS GENERATED		
150	20.5	60	86	135	Generator No.	1 2 3	
147	23.7	75	80	100	Units	5075 82 714	
150	24.0	70	80	100	Total Units Generated 5871		
163	24.0	70	80	100	UNITS USED ON WORKS		
157	24.3	70	82	105	Lighting	80	
160	23.0	70	80	100	Power: feed pumps, air and circulating pumps	580 670	
185	23.2	70	82	100	Motor generator: Input	135	
150	24.2	75	84	100	Output	81 54	
160	24.2	70	82	100	Total Units Used on Works 724		
147	25.0	70	76	85	UNITS SENT OUT		
150	24.8	70	78	100	General Supply	Feeders	
147	24.2	70	80	100		Units	
150	22.0	73	84	110		Total	
154	21.0	77	86	120		Positive	
163	22.5	78	86	115		N° 1, 2, 3 997	
170	23.0	80	84	140	N° 4 654		
167	19.5	80	90	135	Negative		
170	19.6	80	90	130	N° 1, 2, 3 879		
74	22.6	80	98	107	N° 4 660		
70	22.4	80	90	110	Alternating L.T.		
67	21.5	90	90	120	Alternating E.H.T.		
63	22.6	82	90	110	No. 1 975		
70	22.4	80	90	110	No. 2 208		
67	21.5	90	90	120	No. 3 108		
63	22.6	82	90	110	No. 4 175		
70	22.5	80	90	116	No. 4 408		
67	23.0	78	89	107	Total Units Sent Out 5064		
63	21.8	80	90	131			
					SHIFT	Switchboard Attendant	Shift Engineer
Live Bus-Bar to Return Conductor when the Line is Changed at Full Voltage					Night	H. L. Chandler	B. Jones
					Day	P. E. Scott	R. A. Gray
					Evening	C. V. Lewis	J. Wilson
					Approved:	L. S. Newman	Resident Engineer

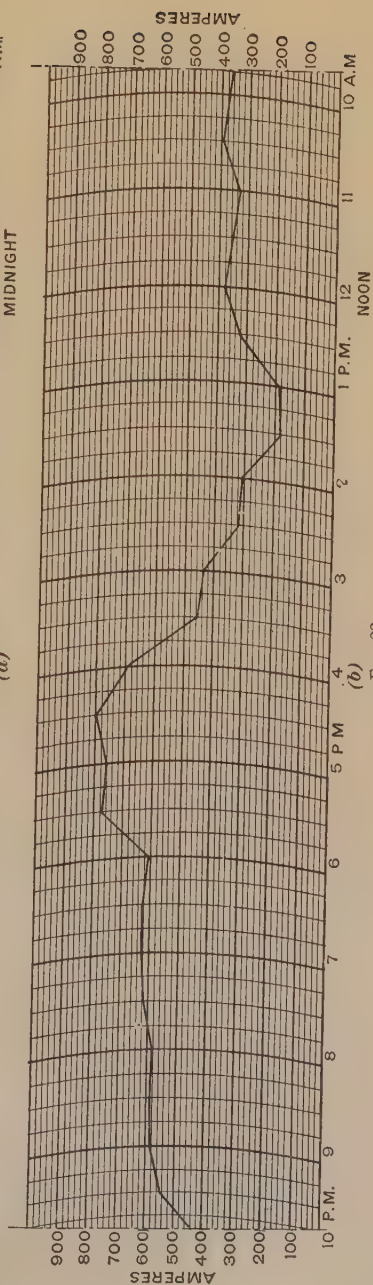
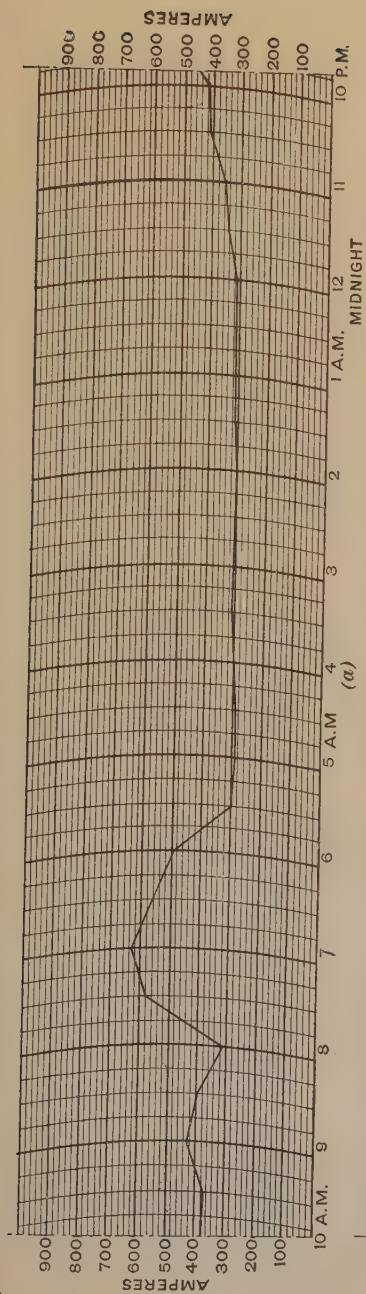


FIG. 22

The last section reports the statutory tests required by the Board of Trade.

72. Generating Machinery.—In the station from which the log shown in Fig. 21 is taken, there are three main direct-current generators, with a combined output of 1,000 kilowatts. The traction supply is at 500 volts on the trolley wire and the lighting supply is given on the three-wire system, with a declared pressure at the consumers' terminals of 460 volts between the outers. The generators are therefore designed so that they will develop 460 to 500 volts, for lighting, when running as shunt-wound machines, or will develop from 500 to 550 volts, for traction, when running as compound-wound machines. As shown in the log sheet, one generator is run on the lighting load; its readings are given on the sheet and are plotted in Fig. 22 (*a*) and (*b*); one generator takes charge of the traction load, indicated by *T*; the third machine is kept as standby or spare. The lighting load is especially heavy. The traction load is so variable that instrumental readings are not entered on the log sheet; a record is obtained, however, by means of a recording ammeter and is reproduced in Fig. 23 (*a*) and (*b*). In each case the curves, which are cut into halves for convenience, show the records for 24 hours.

73. Electrical Records.—The lighting of the power station and the motors driving the feed-pumps and other auxiliary machinery are connected to the three-wire bus-bars, and the current on the + and — sides is entered on the log sheet. The three-wire lighting system is balanced by means of a balancer consisting of three machines coupled together on one shaft. The end machines act as generators or motors, as shown by the + and — signs for the current flowing in them, according to the disposition of the lighting load on one side or the other of the three-wire system. The centre machine may also be driven as a motor from the traction bus-bars. When the traction load is lightest, between 12 o'clock midnight and 5 a.m., the traction generator is shut down, and the traction load is supplied by the centre machine running as a dynamo, while the end machines are motored from the lighting bus-bars. After the balancer readings, succeeding columns give the current in the outers and middle wire of the

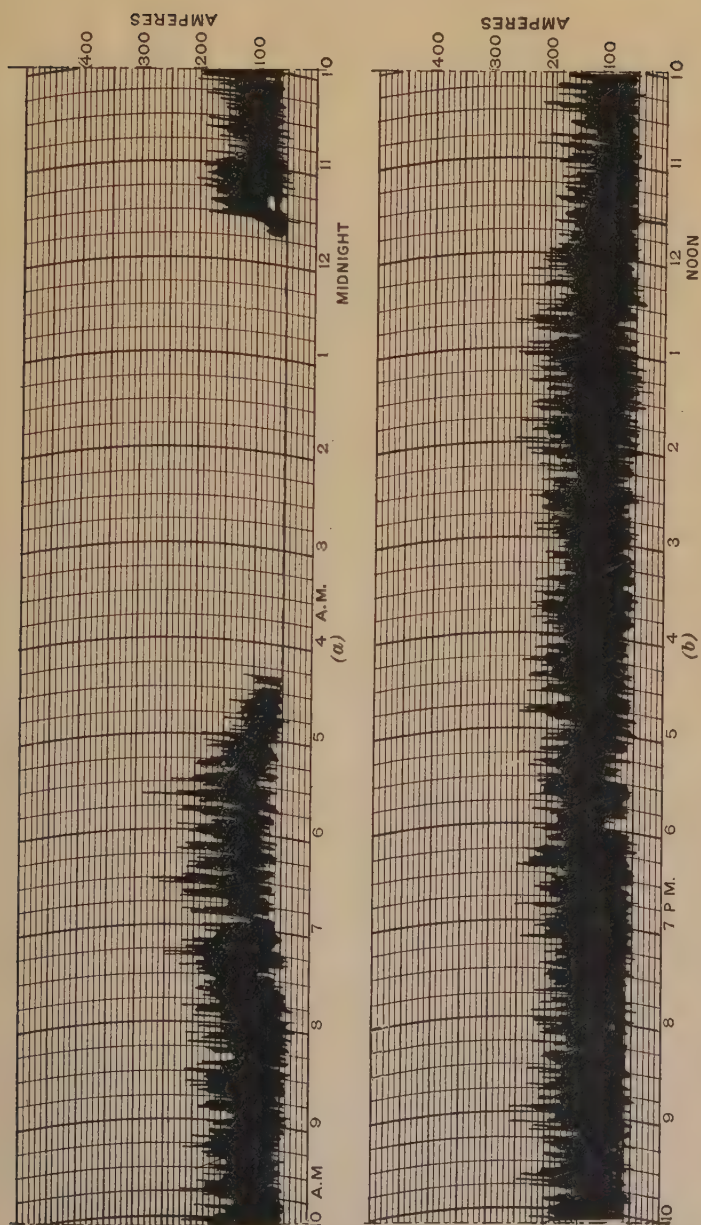


FIG. 23

lighting and general supply feeders, and the current taken by a rotary converter. The last-named machine is motored from the outers of the lighting bus-bars, and, on the alternating-current side, in conjunction with transformers, supplies alternating current for transmission to distant points of the lighting system. The pressure readings show the voltage across the outers of the lighting bus-bars, and the voltage between each outer and the neutral of pilot wires, run to the central point of the lighting load.

74. Steam Plant and Shift Report.—In order to keep a record of the operation of the steam plant in the generating station, one column of the log sheet is allotted to each of the four boilers, and ticks in the proper columns indicate which boilers are kept under steam throughout the day. The following columns show the variations of the boiler steam pressure, the hours during which the steam-driven and electrically driven boiler feed-pumps are working, and the temperature of the feedwater supplied from economizers 1 and 2. For the condensers, the vacuum is given in the equivalent inches of mercury, and the temperatures, in degrees Fahrenheit, of the circulating-water inlet, circulating-water outlet, and the air-pump discharge. The variation of these quantities with the variation of load throughout the day may be studied with advantage. The remarks under the heading of Shift Report show the times at which the generators are started up or shut down and when the switches are opened or shut.

75. Summary of Daily Results.—The section of the log sheet comprising the summary of the daily results is usually entered up by the third, or evening, shift engineer, and its main purpose is self-explanatory. Records are kept of the units generated by each generator, units used on works, and of the units sent out on the various feeders. If desired, the meter readings of the separate watt-hour meters may be entered on the daily log sheet, but otherwise a separate meter book may be kept. The records of maximum load, and of the coal and water used, are clear from the respective headings and the items entered thereunder. A space is reserved at the bottom of the sheet on which to enter the results, daily or weekly as the case may be, of the Board of Trade tests of the traction system.

TRAMWAY TRACKS

TRACK WORK

RAILS AND RAIL ADJUSTMENTS

PRELIMINARY CONSIDERATIONS

1. Necessity for Substantial Construction.—The track on which electric tramcars are to be run must be very substantially constructed. The car wheels drive the car by their reaction on the rails and cause much greater wear and tear than if the cars were hauled by a moving cable or by horses, because the rails are subjected to a grinding action whenever the wheels fail to grip them, and slipping occurs. In addition to this, the driving motors and control gear increase the weight of the car, and consequently the pounding which goes on at rail joints, points, and crossings. The permanent way as constructed for horse tramways was altogether too light for the heavy cars and the rapid acceleration introduced by electric traction, and the track as constructed to-day is as substantial as for main-line steam railways.

2. Gauge.—By the gauge of the track is meant the width between the rails, measured from the outer side of the groove in one rail to the outer side of the groove in the other rail, as shown at *a* in Fig. 1.

The greater number of tramway companies in Great Britain have adopted either the broad or the narrow gauge, the former

being 4 feet $8\frac{1}{2}$ inches and the latter 3 feet 6 inches. An important exception to this is the Glasgow tramways, where the gauge is 4 feet $7\frac{3}{4}$ inches, this width being adopted to allow the railway wagons in connection with the large shipyards to use the tram lines. As the tram lines were extended and new systems constructed in the neighbourhood this gauge was perpetuated. In Great Britain, approximately 50 per cent. of the tramways have adopted the broad gauge, 33 per cent. the narrow gauge, 5 per cent. a gauge of 4 feet $7\frac{3}{4}$ inches, and 7 per cent. a gauge of 4 feet 9 inches, the remaining 5 per cent. having odd dimensions.

The broad gauge is preferable to the narrow gauge, owing to the increased space available for fitting the motors, and also on account of the increased stability given to the car, this point being of special importance where cars with covered top decks

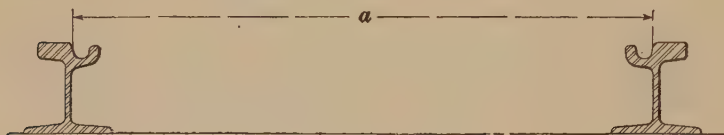


FIG. 1

are in use. The reasons for adopting a narrow gauge is to allow of more clearance on narrow streets when passing standing vehicles, and to reduce the amount of paving to be maintained by the tramway authority, which comprises all the paving between the rails, including the centre way, and an additional 18 inches beyond the outside rails.

3. Single and Double Tracks.—The question as to whether single or double track should be laid depends on the traffic to be expected and also on the width of the roadway. With a sufficient number of passing places, about a 5-minute service can be efficiently maintained on a single track, but there is always present the danger of collisions taking place, especially in foggy weather. Where the roadway is narrow and the cost of widening it prohibitive, a single track is sometimes put down for a service quicker than one car each way every 5 minutes, because if double track were put down with insufficient room

for a cart to stand at the side of the road, both the running of the cars and the ordinary traffic would be seriously interfered with. The two tracks of a double-track system must be laid such a distance apart as to give at least 15 inches clearance between the cars.

The position of the passing places, or turnouts, requires careful consideration. They must be so placed that the driver has a clear view of the whole of the stretch of single track in front of him, or if this is impossible, owing to bends in the road, electric signals must be fitted.

SPECIFICATION OF STEEL FOR RAILS

4. Composition of Rails.—Tramway rails are made of mild steel, that is, steel with low percentages of carbon, manganese, silicon, phosphorus, and sulphur. The percentages of carbon and silicon have a marked effect on the hardness of the rail. If the percentages of these elements are too small, the rail will be soft and the wearing qualities poor; if too high, the rail will be brittle. The following are the percentages of the various elements recommended by the Engineering Standards Committee: Steel suitable for rails should contain $\cdot 40$ to $\cdot 55$ per cent. of carbon, $\cdot 7$ to $1\cdot 0$ per cent. of manganese, and not more than $\cdot 10$ per cent. of silicon, $\cdot 08$ per cent. of phosphorus, and $\cdot 08$ per cent. of sulphur.

5. Effects Produced by the Various Elements.—The effects produced by the various elements in steel are shown in Table I. It will be noted that the percentage of manganese is relatively high; this gives a rail which is hard, yet ductile, and of good wearing qualities.

6. Sandberg Rails.—It has been found that rails containing a high percentage of silicon give excellent wearing results, but have the disadvantage of being very brittle. Mr. C. P. Sandberg, who has made a special study of this subject, found that the effect of silicon, when added, is entirely different from the effect of silicon left in from the pig iron. When the percentage of silicon left in exceeds the amounts specified in Table I, it causes

brittleness, but when the silicon is first eliminated, and a certain known quantity is afterwards added, the effect is to toughen the steel. Rails made to the Sandberg specification, containing 5 to 10 times the amount of silicon generally found in Bessemer

TABLE I
EFFECTS PRODUCED BY VARIOUS ELEMENTS IN STEEL

Element	Purpose for Which Element is Required	Variation of Percentage Present	Effect Produced if Present in Excess
Carbon . .	To give requisite amount of strength and hardness	·4 to ·7	Makes the metal brittle, and liable to fracture under shock or large change of temperature
Manganese .	To give ductility	·70 to 1·0	Greatly reduces conductivity, and makes metal too malleable
Silicon . . .	To make metal dense and compact, and give fluidity when molten	·066 to ·25	Makes metal brittle
Phosphorus .	Undesirable, but costly to eliminate	·05 to ·11	Makes metal brittle
Sulphur . .	Undesirable, but costly to eliminate	·05 to ·07	Makes metal seamy

or open-hearth steel, have been tried on several railways and tramways, and reports which have recently been published show a life twice that of ordinary rails. The cost of manufacture is, however, greater than for ordinary rails.

RAIL SECTIONS

7. British Standard Sections.—The section of tramway rail adopted in Great Britain is the grooved girder rail shown in Fig. 2, where *a* is the flange, *b* the web, *c* the tread, *d* the check, and *e* the groove. Five different sections of this have been standardized by the Engineering Standards Committee for

straight-line work, and five for curve work, the latter varying from the former in the width and depth of the groove. For straight-line work the groove is $1\frac{1}{8}$ inches wide by $1\frac{1}{8}$ inches deep, and for curve work $1\frac{1}{4}$ inches wide and $1\frac{1}{4}$ inches deep. The various sections are known as British Standard No. 1, No. 2, etc., usually abbreviated to B.S. No. 1, etc., the curve sections having the letter *c* after the number. The weights of the various sections, with the depths of the sections and the widths of the flanges, are given in Table II.

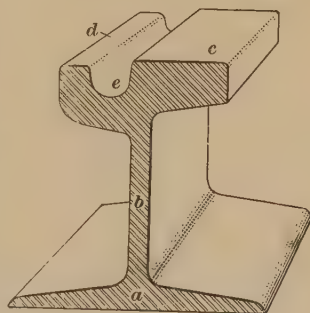


FIG. 2

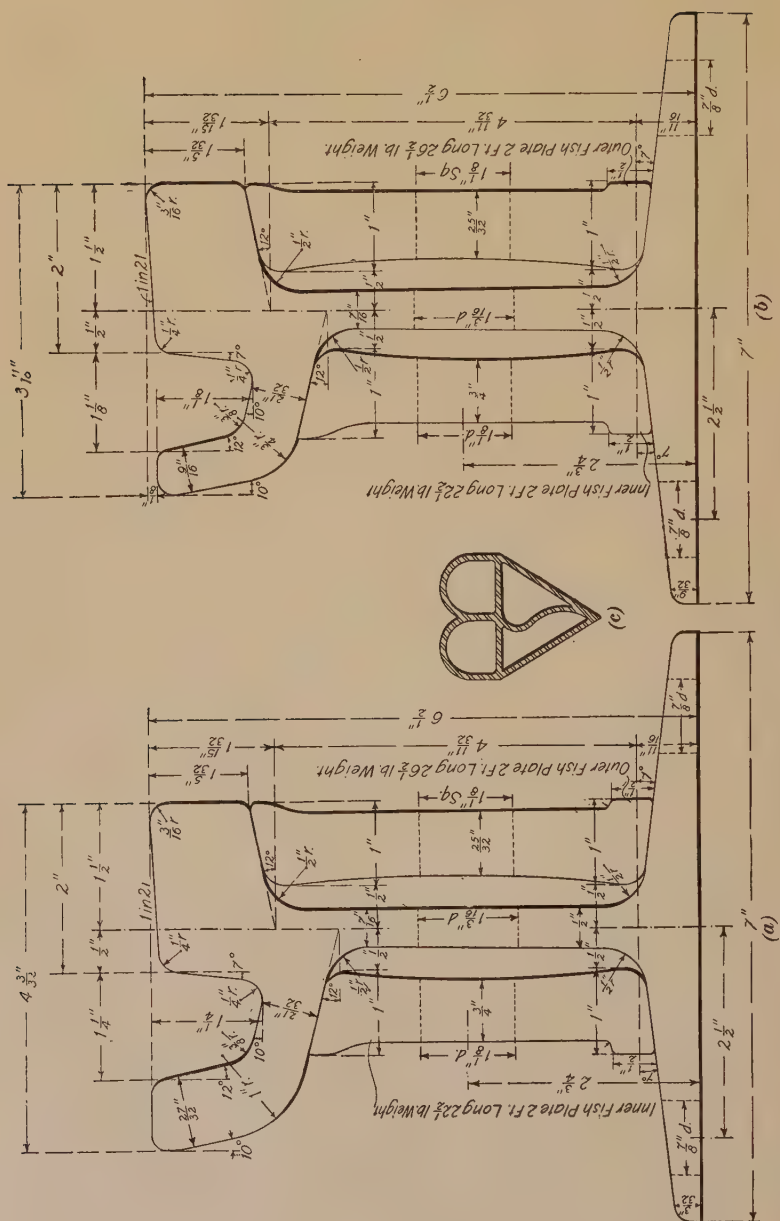
TABLE II

STANDARD TRAMWAY-RAIL SECTIONS AND WEIGHTS

British Standard Rail Section Number	Weight Pounds Per Yard	Depth of Section Inches	Width of Flange Inches	British Standard Rail Section Number	Weight Pounds Per Yard	Depth of Section Inches	Width of Flange Inches
1	90	$6\frac{1}{2}$	$6\frac{1}{2}$	3c	106	$6\frac{1}{2}$	7
1c	96	$6\frac{1}{2}$	$6\frac{1}{2}$	4	105	7	7
2	95	$6\frac{1}{2}$	7	4c	111	7	7
2c	101	$6\frac{1}{2}$	7	5	110	7	7
3	100	$6\frac{1}{2}$	7	5c	116	7	7

8. Standard templates are in the hands of the different makers, so that rails to the weights and dimensions given can always be procured by giving the section number. This standardizing of rail sections has been a great boon to the rail manufacturers as well as a convenience to the users, as it reduces the number of rolls which have to be kept in stock and also the cost of production.

The standard sections B.S. No. 3 and No. 3c are shown in Fig. 3 (a) and (b), most of the principal dimensions being given. For a complete list of dimensions, including those of the various fillets and corners, the report of the Engineering Standards



Committee should be consulted. All standard rails are branded as shown in Fig. 3 (c), and have, in addition, the section number, the weight per yard, the names of the maker and purchaser, and the date of supply. The rails are usually supplied in 35-, 45-, and 60-foot lengths.

9. Cross-Section and Weight of Rails.—Rails are always referred to by their weight, in pounds per yard. Thus, a rail weighing 60 pounds per yard is known as a 60-pound rail; one weighing 80 pounds per yard, as an 80-pound rail; and so on. The weight, in pounds per yard, divided by 10 gives approximately the cross-sectional area, in square inches. For example, an 80-pound rail would have a cross-sectional area of $\frac{80}{10} = 8$ square inches.

Let A = area of rail section, in square inches;

W_y = weight of rail, in pounds per yard.

$$\text{Then,} \quad A = \frac{W_y}{10} \quad (1)$$

Rule I.—*To find the area of cross-section of a rail, in square inches, divide the weight, in pounds per yard, by 10.*

To find the weight of rails, neglecting tie-bars, fish-plates, bolts, etc., required per mile of single track, the following simple formula may be used:

Let W_t = weight of rails, in tons, for 1 mile of single track;

W_y = weight of rail, in pounds per yard.

$$\text{Then,} \quad W_t = 1.57 W_y \quad (2)$$

Rule II.—*The number of tons weight of rails required for 1 mile of single track is equal to 1.57 times the weight of the rail per yard, in pounds.*

10. Wheels and Rails With Bevelled Tread.—It has been found advantageous to make the treads of the car wheels slightly conical; that is, the diameter of tread next to the flange is larger than its diameter at the outside edge. This is done to allow the car to adjust itself on the track when the two wheels on the same axle are not exactly of the same size. This construction probably performs its function when there is no greater difference in the wheels than is found on two wheels of the same make just as they come from the foundry; this difference

is, as a rule, not more than $\frac{3}{8}$ inch in the circumference. The bevelled tread cannot, however, be expected to have much equalizing effect in cases where the difference in diameter of the two wheels is $\frac{3}{8}$ or $\frac{1}{2}$ inch.

It will be observed that, in order to give a good traction surface between the wheels and the rail, the rail tread is bevelled

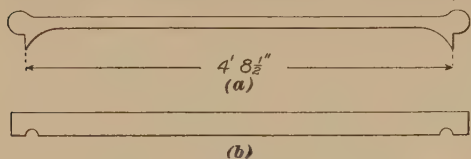


FIG. 4

to suit the wheel, the amount of slope or bevel being 1 in 21, as indicated in Fig. 3 (a) and (b).

11. Rail Grooves and Wheel Flanges.—For a given groove there is always a given shape of car-wheel flange that is best suited to that groove, so that, when buying car wheels, care must be taken that the flanges are of suitable shape, otherwise there will be excessive wear in the groove and on the wheel flange. A wheel flange must be of a certain depth in order to keep the car on the track; if the depth of the groove and the depth of the flange of the wheel are about the same, the least bit of wear in the tread of the wheel will allow the weight of the car to rest on the flange, which is not designed to carry

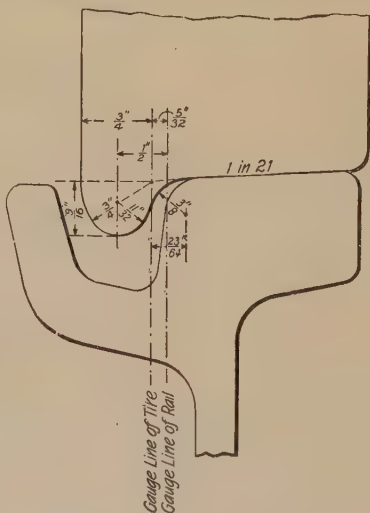


FIG. 5

it. If the wheel flanges are deeper than the groove, the wheels cannot be used at all. A track of the ordinary grooved rail must be gauged with great exactness, because a variation in either direction will cause the wheels to bind. If the gauge is too narrow, the outsides of the wheel flanges bind against the sides of the rail treads; if the rails are too far apart, the insides of the wheel flanges bind against the side of the rail check.

GAUGE MEASUREMENT AND RAIL ADJUSTMENT

12. **Gauge Measurements.**—The gauge of the track is measured by a *track gauge*, as shown in Fig. 4 (a), and the distance between the car wheels is measured by a *wheel gauge*, as shown in Fig. 4 (b). Fig. 5 shows a section of a car tire in position on the rail, the vertical dotted lines showing the points to which the gauge measurements are taken. The gauge of the wheels is slightly less than the track gauge in order to prevent binding, the wheel gauges for a 4' 8½" track gauge being 4 feet 8⅜ inches, and for a 3' 6" track 3 feet 5⅜ inches. The width of tires recommended for the different rail sections is given in Table III.

TABLE III
WIDTH OF WHEEL TREAD
FOR BRITISH STANDARD
RAILS

British Standard Rail Section Number	Width of Tire Inches
1 and 1c	2⅞
2 and 2c	2⅜
3 and 3c	3
4 and 4c	3⅛
5 and 5c	3¼

13. **Tie-Bars.**—In order to keep the rails true to gauge they are fastened together every 6 to 12 feet with *tie-bars* or *tie-rods*, which usually consist of bars of steel of rectangular section, terminating at one or both ends in a screwed rod carrying nuts

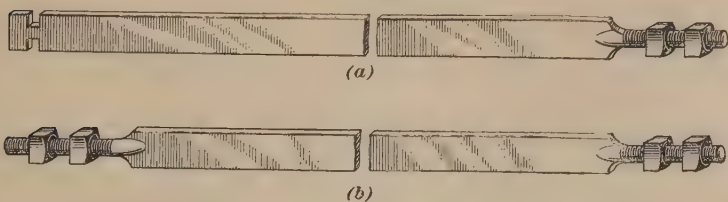


FIG. 6

and washers. Sometimes the tie-rods are circular throughout the whole of their length. The two most common types of tie-bars are shown in Fig. 6 (a) and (b). The variety shown in Fig. 6 (a) is known as the single-ended type, one end only being screwed, and the other end furnished with slots, as shown.

Fig. 6 (b) shows the double-ended type, which is screwed at both ends. To enable the tie-bars to be attached to the rails,

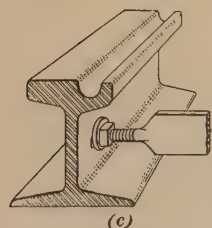
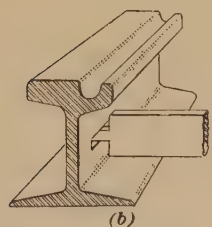
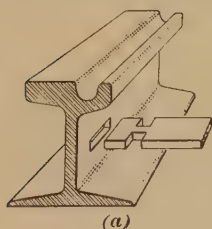


FIG. 7

slots 2 to 3 inches long are punched in the webs of the rails at the desired intervals. If the single-ended tie-bar is used, the notched end is pushed sidewise through the slot, as shown in Fig. 7 (a), and is then turned round into the position shown in Fig. 7 (b), all adjustments being made from the other end by means of the nuts. The way in which the double-ended type is attached to the rail is shown in Fig. 7 (c); with this type of tie-bar, adjustment can be made from either end.

14. The sizes and weights of standard steel tie-bars for broad- and narrow-gauge tracks are given in Table IV. The number of tons of tie-bars required per mile of single track is calculated on the assumption that the tie-bars are placed 7 feet 6 inches apart. For example, the number of tie-bars per mile of single track is $\frac{5,280}{7.5} = 704$. For

a track having a gauge of 4 feet $8\frac{1}{2}$ inches, the weight of one tie-bar $2\frac{1}{2}$ inches by $\frac{3}{8}$ inch is $16\frac{1}{2}$ pounds. The number of tons required per mile will therefore be $\frac{704 \times 16\frac{1}{2}}{2,240} = 5.18$, as shown by the table.

TABLE IV
SIZES AND WEIGHTS OF STANDARD STEEL TIE-BARS

Gauge of Track		2 Inches by $\frac{1}{4}$ Inch		2 $\frac{1}{2}$ Inches by $\frac{1}{4}$ Inch		2 Inches by $\frac{3}{8}$ Inch		2 $\frac{1}{2}$ Inches by $\frac{3}{8}$ Inch	
Ft.	In.	Weight of Each Pounds	Tons Per Mile	Weight of Each Pounds	Tons Per Mile	Weight of Each Pounds	Tons Per Mile	Weight of Each Pounds	Tons Per Mile
3	6	$9\frac{1}{2}$	2.98	11	3.46	11	3.46	13	4.08
4	$8\frac{1}{2}$	12	3.77	14	4.4	14	4.4	$16\frac{1}{2}$	5.18

RAIL ANCHORS

15. Inverted-Rail Anchor.—In order to prevent any motion between the rails and the concrete foundation of the permanent way it has become customary, in recent constructions, to fasten the rails to the concrete at intervals by means of projections called **rail anchors**, which are bolted to the rail flange and embedded in the concrete. A simple and effective method of doing this is to bolt or rivet a short length of old rail to the under side of the track rail, flange to flange, as shown in Fig. 8, where *a* is the track rail, and

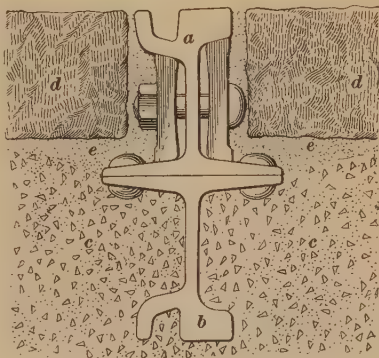


FIG. 8

b the old rail section riveted to *a* and embedded in the concrete *c*. The granite setts are shown at *d*, and the space *e* between the rail and the setts is filled in with cement. When these anchors are used at joints between the rails, they are 24 inches long; but when used at intermediate positions, the length is 18 inches. Anchors of this kind are used about every 20 feet.

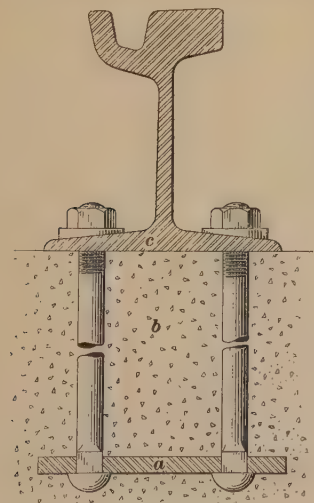


FIG. 9

16. Other Types of Anchors.

Another simple type of rail anchor is shown in Fig. 9. It consists of a steel plate *a* embedded in the concrete *b* and bolted to the rail flange *c* by means of two 8-inch bolts. A type of rail anchor which gives an exceedingly rigid track consists of lengths of channel iron or old rail placed across the track and bolted to the rails to form sleepers, as shown in Fig. 10,

where the track rails are lettered *a* and the transverse sleeper

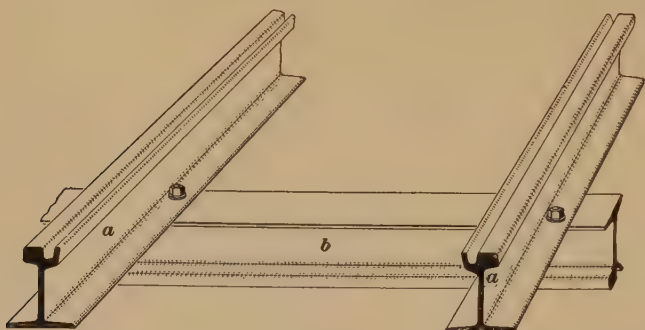


FIG. 10

of old rail *b*. This sleeper is embedded in the concrete on which the track rails stand, as in the previous cases.

DRAIN RAILS

17. Serious trouble is often caused in wet weather by the large amount of water which flows along the grooves of the rails. The water sometimes finds its way between the rail joints, and flows down to the concrete bed on which the rails

rest; if this water freezes, it damages the track by lifting and loosening the paving and joints.

In order to get rid of the water, **drain rails**, which carry the water to the sewers, are inserted in the track at intervals.

Fig. 11 shows a section of a drain rail. The tread of the rail is at *a*, and a slot about 12 inches long is cast in the bottom of the groove, as at *b*, to allow the water flowing along

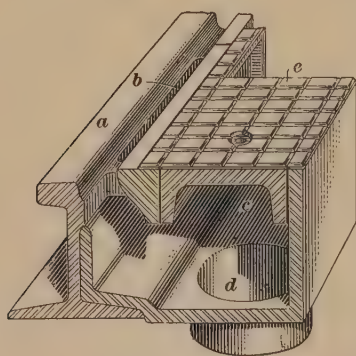


FIG. 11

the rail to fall into the box *c*, and thence to the sewer by the pipe *d*. The box *c* is provided with a removable lid *e*, so that the pipe *d* can be kept clear of mud. Under ordinary conditions,

however, the device is practically self-cleaning, and requires very little attention. The drain rail is usually from 6 feet to 8 feet 6 inches long, and is attached to the regular track rails in the usual way by means of *fish-plates*.

RAIL JOINTS

MECHANICAL JOINTS

18. Fish-Plate Joint.—No part of the permanent way requires greater care than the rail joints; in fact, the life of the rail is often limited by the life at the joint. If there is any looseness or unevenness, the pounding of the car wheels soon flattens the rail at the ends, and once the flattening has started the rate of deterioration increases greatly.

The usual method of jointing the rails is to bolt them together by means of channel-shaped strips of steel, called *fish-plates*, as shown in Fig. 12, where *a* and *b* are the two rails to be jointed, and *c* is

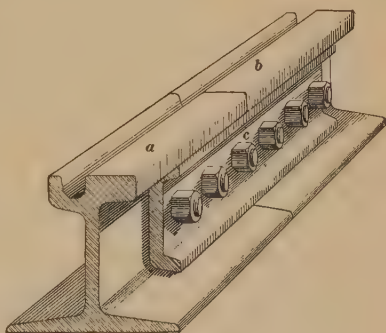


FIG. 12

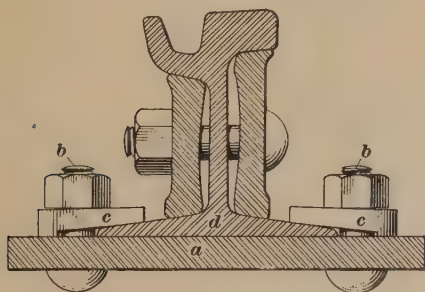


FIG. 13

one of the fish-plates. One fish-plate is used on each side of the web, as shown in Fig. 13, which gives a sectional view of the fish-plates and rails. The fish-plates are secured to the rail by six bolts, three in each rail; they are spaced 4 inches apart, the first bolt being 2 inches from the end of the rail. Where the rails

are joined, the rails are usually supported by a single set of chairs, and the joint is made so that the rails are in line.

are $6\frac{1}{2}$ inches deep the centre line of the bolts is $2\frac{3}{4}$ inches from the under side of the flange,

TABLE V
WEIGHTS OF FISH-PLATES FOR
STANDARD RAILS

British Standard Rail Section Number	Weight of Inner Fish- Plate Pounds	Weight of Outer Fish- Plate Pounds
1 and 1c	$22\frac{1}{2}$	$27\frac{1}{2}$
2 and 2c	$22\frac{1}{2}$	27
3 and 3c	$22\frac{1}{2}$	$26\frac{1}{2}$
4 and 4c	26	$30\frac{1}{2}$
5 and 5c	26	$30\frac{1}{2}$

the under side of the flange, and for 7-inch rails the distance is 3 inches. Fish-plates for standard rails are 24 inches long, and the weights for the various sizes of rails are given in Table V.

19. Sole - Plate Joint.

In order further to strengthen the joint, flat plates of steel, called **sole plates**, are often attached to the bottom of the flange of the track rail, as shown

in Fig. 13, where *a* is the sole plate, fixed by means of the bolts *b* and clips *c* to the flange *d*. Compared with the fish-plates, the sole plate, which is usually made about 1 inch thick, offers but little resistance to bending, and is often replaced by a short length of steel joist or old rail bolted flange to flange with the running rail, as described in connection with rail anchors.

20. Continuous Joint.—A type of joint known as the continuous joint is illustrated in Fig. 14. It

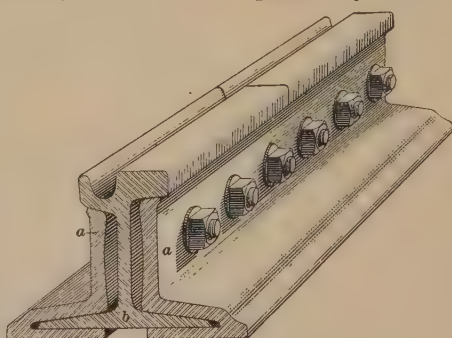


FIG. 14

consists of a combination of fish- and sole plates, the fish-plates *a* being extended and taken under the flange *b* of the track rail, making the joint rigid, and keeping the rails alined.

21. Rail Expansion.—Rails are subjected to considerable variations in temperature, which cause corresponding changes

in their lengths. On ordinary steam- or electric-railway lines, where there is no paving, expansion is allowed for by making the bolt holes in the rails in the form of slots, so that the rails can move slightly in a horizontal direction between the fish-plates. Thus, in cold weather there will be a gap of perhaps $\frac{1}{4}$ to $\frac{5}{16}$ inch between the rail ends, while in warm weather there will be scarcely any space at all. Mild steel expands $\cdot0000117$ of its length for each degree centigrade increase in temperature. Assuming that the extreme difference in temperature to which the rail is subjected is $55\cdot5^{\circ}$ C., a track would be $\cdot0000117 \times 55\cdot5 = \cdot00065$, approximately, of its length longer in the hottest weather than in the coldest.

A stress of 1,000 pounds per square inch will stretch a mild-steel bar $\cdot00003$ of its length. Hence, if a rail is stretched $\cdot00065$ of its length, the stress per square inch of cross-section of the rail will be $\frac{\cdot00065}{\cdot00003} \times 1,000 = 21,666$ pounds. If the rails are

continuous and firmly anchored, so that there is no play at the joints, the track as a whole cannot expand and contract, so that the force of expansion must be taken up by putting stress on the rails. The rails will tend to expand with increase in temperature, thus causing compressive stresses; and on tending to contract with decrease in temperature, the rails will be stretched, but the stresses so caused will not exceed 22,000 pounds per square inch under the conditions assumed. A safe value for the elastic limit of steel is 40,000 pounds per square inch; that is, steel subjected to any stress below this amount will not take a permanent set, but will return to its original length when the stress is removed.

22. For the foregoing reasons, if a track is constructed so that it cannot buckle sidewise and get out of line, there is no objection to butting the ends of the rails together and fastening them by means of some form of joint that allows no longitudinal motion whatever. In paved streets this condition is met, and it is now common practice to use methods of rail joining that give a continuous rail. Jointless rails reduce wear on both rolling stock and track by giving a smooth running surface.

When the rails are embedded in paving, the surface exposed to the atmosphere is small and the rails are therefore not subjected to such rapid or extreme variations of temperature as on open tracks. There are a number of types of solid joint, the most important being the *cast-welded*, the *electrically welded*, and the *thermit*, of which the last is the most commonly used.

CAST-WELDED JOINT

23. Falk Joint.—A rail joint made by pouring molten cast iron into a mould which surrounds the abutting ends of the rails is generally known as the **Falk cast-welded joint**. The ends of the rails are first thoroughly cleaned for a distance of 6 or 8 inches on each side of the joint by means of a sand blast. A cast-iron mould is then clamped round the rail ends and molten iron poured in, thus forming a joint. In order to make these joints, a considerable amount of apparatus is required, a portable cupola for melting the iron and a sand blast for cleaning the rails being essential. To make the joints at all reasonable in cost, a large number must be made at a time. The weight of iron varies from 70 to 140 pounds, depending on the shape of the joint and the section of the rail.

24. It is usual practice to shape the mould so that the iron cast round the rail joint will have no sharp corners or edges. Fig. 15 (a) and (b) shows the section and side view of a common

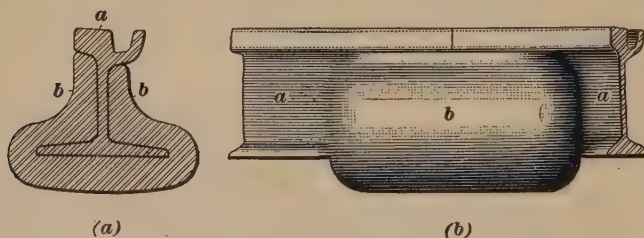


FIG. 15

form of Falk joint, the rail being lettered *a* and the cast iron *b*. In cast welding, the iron used is of a special chemical composition, and is poured at a much higher temperature than that used when making ordinary castings. The effect of this is that the cast

iron fuses into the surface of the steel rail, thus forming a joint that is strong mechanically and of high conductivity. It is claimed by some that cast welding anneals the ends of the rail, thus softening them and causing them to pound or flatten out more than the rest of the rail ; but on a number of tracks where the cast-welded joint has been in use for several years, no bad effects from this cause have been noticed.

ELECTRICALLY WELDED JOINT

25. Equipment for Electric Welding.—The method of making electrically welded joints, as introduced by the Lorain Steel Company, consists in welding bars to each side of the web of the rail by passing a very large electric current through the bars and rail. Quite an elaborate outfit is required for this process, which, like cast welding, is only applicable where a large number of joints are to be made. The outfit consists of four cars : first, a sand-blast car ; second, the car carrying the welder ; third, a car attached to the welding car and carrying the rotary converter and transforming apparatus for supplying the welder with alternating current ; fourth, a car provided with machinery for grinding off the rail treads after the joints have been welded. The cars are arranged in the order named. The first car contains a sand-blast tank and a motor-driven air compressor for operating the blast by means of which the web of the rail and the surfaces of the plates are thoroughly cleaned before the welding operation takes place.

26. Splice Bars.

To make the joint, a mild-steel plate, similar to that shown in Fig. 16, is welded on each side of the web ; the finished joint ap-

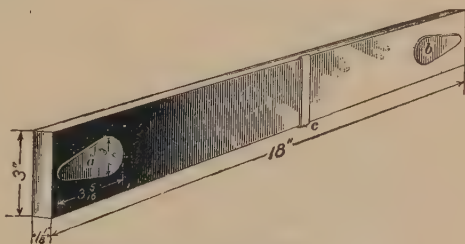


FIG. 16

pears as shown in Fig. 17. Each bar is welded in three places corresponding to the raised parts *a*, *b*, *c*, Fig. 16. The bosses *a*, *b*

at the ends of the bar are formed under a drop hammer, which forces the metal in on one side and out on the other, the depression on one side being afterwards filled with a piece of metal

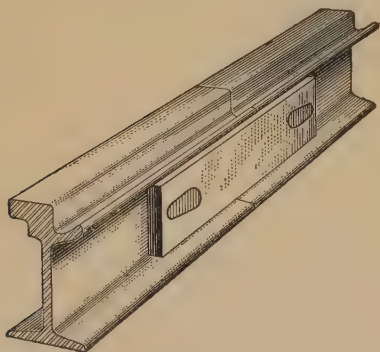


FIG. 17

The boss at *c*, which comes opposite the joint between the rails, is made by welding a small strip of steel over the bar. The object of the bosses is to localize the welding current and thus confine the welding to a certain area; each boss has an area of about $3\frac{1}{2}$ square inches, so that the welded area on each bar is about $10\frac{1}{2}$ square inches, or 21 square inches for the two

bars. After the rails have been cleaned, lined up carefully, and the bars wedged in position, the joint is ready for welding by means of the electric welder suspended from the front of the second car.

27. Action of Welder.—The main parts of the welder and their relation to the joint are shown in Fig. 18. The two splice bars *a, a* are located so that the centre boss comes opposite the end of rail *b*. The terminals *c, d* of the welding transformer *e* are pressed against the splice bars by means of levers *f, g* that are pushed apart at their upper ends by pistons working in a hydraulic cylinder *h*. Just sufficient pressure is applied to hold the bars in place and provide good contact.

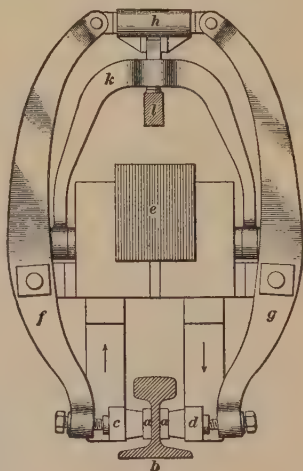


FIG. 13

The secondary of the transformer consists of a single loop of very heavy conductor, so that a very large current at low pressure is delivered. The whole welding apparatus is

suspended from a yoke k carried by an arm l extending from the front of the car and arranged so that the welder can be moved in any direction to permit an easy and rapid adjustment to the joint. The primary of the transformer is supplied with alternating current obtained from a rotary converter placed in the third car and driven by direct current from the trolley wire. Suitable regulating devices are provided so that the voltage applied to the welder can be maintained fairly constant, even though the trolley voltage varies considerably.

28. Method of Making Joint.—The weld in the centres of the bars is made first. In about $2\frac{1}{2}$ minutes after the current is turned on, the joint is brought up to a welding heat; the current is then cut off and the pressure on the joint increased by the hydraulic cylinder h , the maximum pressure applied being about 35 tons. After a few moments, the pressure is released and the welder adjusted to one of the end welds, where the process is

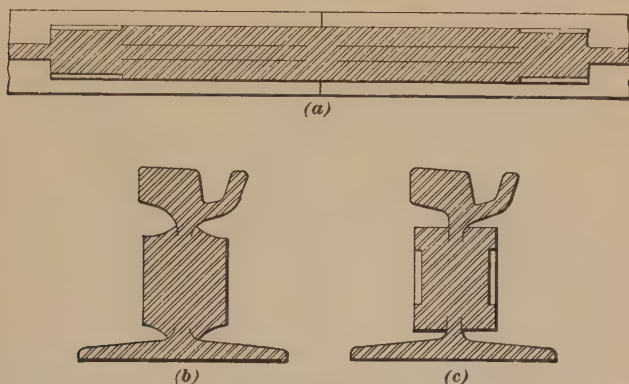


FIG. 19

repeated, only, with both end welds, the heavy pressure is maintained until the metal has cooled below a glowing heat; it has been found that this makes the weld tougher. Since the middle weld is made first, the bars become expanded because of the heat, and since the end welds are made before the middle weld has cooled off, the ends of the bars are fastened to the rail while the metal is expanded. Hence, as the bars cool, the ends of the rail are pulled together, thus making a very close joint

between the rail ends. Fig. 19 (a) shows a horizontal section of a completed joint ; (b) and (c) show vertical sections, (b) being a section of the centre weld and (c) of an end weld.

29. The secondary of the welding transformer develops a pressure of about 7 volts, and the current used for a weld is about 25,000 amperes. The secondary voltage, however, drops somewhat when this large current is flowing, so that the power actually taken from the line is not as great as $25,000 \times 7 = 175$ kilowatts. As a general rule, about 125 kilowatts for $2\frac{1}{2}$ minutes is sufficient for welding an ordinary joint. On the average, about 80 joints can be made in 24 hours ; as a continuous process, working day and night, it takes from 13 to 15 minutes per joint.

The electrically welded joint is very strong, and, when tested, rails seldom pull apart at the point of welding. Also, the head of the rail is not made hot enough to soften it, and the splice bars do not occupy much room.

THERMIT-WELDED JOINT

30. **Action of Thermit in Producing Heat.**—A method of making solid rail joints which is now much used is the **thermit process**, invented by Dr. Hans Goldschmidt. It has shown remarkably good results and gives a joint equal to the rail in conductivity. Careful measurements have shown that the wear at the joints after a year's service does not exceed, appreciably, the wear on the rail.

Thermit is a mixture of finely divided iron oxide and aluminium. The metal aluminium has a great affinity for oxygen, and if this mixture is given a local initial heating by so-called *ignition powder*, a very rapid chemical reaction takes place throughout the whole mixture, and a large amount of heat is liberated. The iron oxide gives up its oxygen to the aluminium, and aluminium oxide is formed ; at the same time the iron oxide is reduced to pure iron. The heat produced by the reaction is so intense that the mass of molten iron has a temperature of about $3,000^{\circ}\text{C.}$, and if poured round a properly prepared rail joint a perfect weld will result.

31. Equipment for Thermit Welding.—The appliances required for making a joint by this process are very simple and easily moved from place to place ; the cost per joint is practically the same whether a few or many are made, and in this respect the process possesses an advantage over cast welding and electric welding, which are practically out of the question if only a few joints are to be made. Fig. 20 shows a rail joint made with thermit, and Fig. 21 shows the

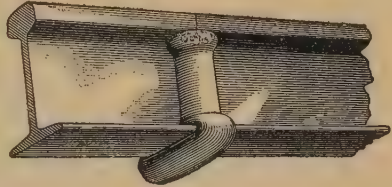


FIG. 20

moulds that are clamped on either side of the rail to receive the melted metal. These vary in form according to the shape of the rail section, and are made by placing a sheet-iron case (*b*) over a model, or pattern, of the joint and tamping it full of a good quality of sand. The moulds for the two sides of a rail are shown in (*a*) and (*c*). The edges of the mould are smeared with clay, so

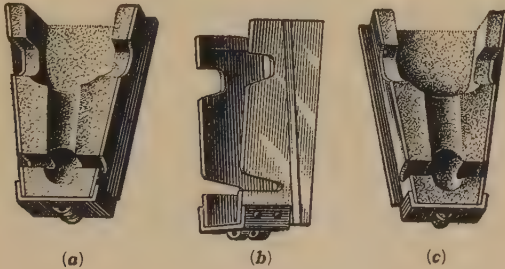


FIG. 21

as to form a tight joint, and the halves are then clamped into position on the rails. The thermit compound is placed in a cone-shaped crucible mounted on a projection from the rail clamps directly over the mould ; about 20 pounds of thermit is used for each joint, the exact amount required depending on the size of the rail. The crucible is composed of an iron case lined with magnesia, and the bottom is formed of a hard magnesia stone provided with a renewable outlet that will stand about five runs. The hole in the outlet is stopped by a plug.

32. Method of Making the Joint.—The ends of the rails to be welded are first well cleaned with a fine flat file and emery cloth. The rails are then fixed firmly end to end by means of powerful clamps, care being taken to get them exactly level and in line. The joint is next thoroughly heated up, by means of blow lamps, to ensure that there is no moisture present. When the rails are so hot that they can hardly be touched by the hand, they are brushed vigorously with a hard steel-wire scratch brush, and the moulds are adjusted and fixed in position on the rails. The rail

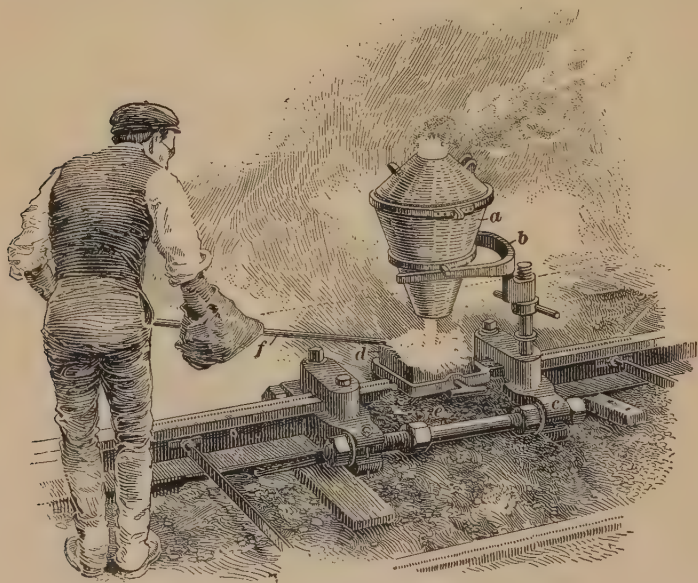


FIG. 22

head and groove should be protected from contact with the molten steel by a thin coating of clay. Both the sand surfaces of the mould, and the clay used for protecting the rail, should be thoroughly dried off by means of a blow lamp before the weld is made. If any moisture is present either on the rail ends or in the mould or clay, steam will be given off when the weld is made, and the metal will be rendered porous. All joints between the mould and the rail are filled with clay, and sand and earth are packed round the mould.

33. When the mould is in place, the crucible is fixed in the holder, with its outlet exactly above the runner of the mould and 6 or 7 inches from it. A small amount of ignition powder is then placed on top of the thermit and lighted by means of a match ; in a few seconds the chemical reaction is over and the lower part of the crucible contains a mass of liquid steel at very high temperature, while the slag, consisting of aluminium oxide or corundum, floats on top. The crucible is then tapped by knocking the plug in the bottom upwards with a flat-ended iron rod, and the steel runs into the mould in a $\frac{1}{2}$ -inch stream. The weight of steel obtained from the reaction is one-half the weight of the

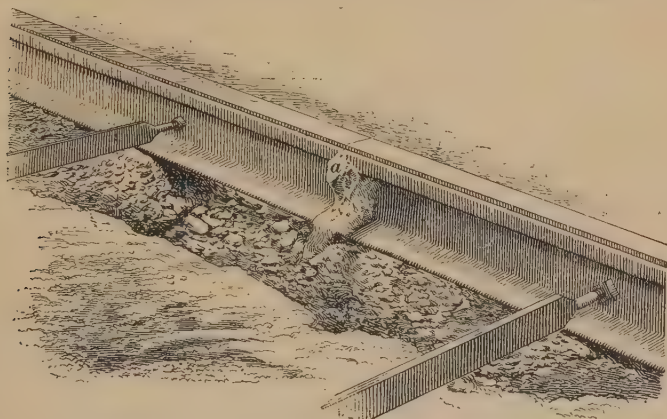


FIG. 23

thermit mixture. The mould is made so that the metal strikes the under part of the rail first and works its way up to the top, thus carrying up any dirt or slag that may be present. The steel is so extremely hot that it alloys instantly with the ends of the rail, and as substances such as manganese or silicon are generally incorporated in the thermit mixture, the steel has approximately the same composition as the rail. After the metal becomes solid, the moulds may be removed. Any surplus metal should be hammered, while still hot, under the head and check of the rail.

34. Fig. 22 shows the operation of making a weld. The crucible *a* is supported in the holder *b*, which is attached to the powerful clamp *c* used for forcing together the rail ends. The

mould is clearly seen at *d*, the lower part of it being surrounded by sand and earth as shown at *e*. The bar with which the crucible is tapped is shown at *f*. It is advisable for the men employed in making the welds to wear spectacles with dark glasses, as the glare from the molten steel is very vivid, and is likely to injure the eyes. Fig. 23 shows a completed joint, immediately after the removal of the moulds, before the metal has been hammered. It will be seen that the space occupied by the band of steel *a* round the weld is very small.

RAIL CORRUGATION

FORMATION OF CORRUGATIONS

35. Probable Cause.—One serious permanent-way trouble which has followed the introduction of electric traction is what is called **rail corrugation**, which is the formation on the tread of the rail of small waves commonly from $1\frac{1}{2}$ to 4 inches between the crests, which are at right angles to the rail length. These corrugations may be up to 30 inches long.

Many theories have been put forward as to the cause of corrugation, the most common laying the blame on the method of rail manufacture, on the method of laying the track, or on the rolling stock running over the lines. As regards the rail manufacture, it has been pointed out that the cause might be due to the use of obsolete machinery for rolling the rails, the worn gear-wheels of which caused a chattering action to take place, which produced the wavy effect on the rail tread. The absence of corrugation on steam railways in Great Britain has led others to think that the cause of the trouble was the rigid construction of the track, and a resilient track was suggested. A third theory assigns the blame to the rolling stock, suggesting that the trouble is due to defective trucks, in which the axles are not at right angles to the track. It is also suggested that this causes unequal wear on the wheels, and, as the wheels are fixed rigidly to the axle, one of them must skid slightly to revolve at the same rate as the other, thus grinding the rail into waves.

36. In order to test whether or not the trouble was due to the rails, experiments have been made by interchanging a smooth rail and a corrugated one. The result was that the corrugated rail became smooth and the smooth one corrugated. This test practically cleared the rails of any responsibility in the matter.

The question of making the track flexible is one which is decided at once by the paving. If the track were flexible, the paving could not be kept in order, as the paving blocks of wood or other material would be worked out of position and would be a continual source of trouble. In addition to this, the forces due to rail expansion necessitate a rigid track.

The whole question is being carefully studied, and at present conclusions seem to point to intermittent skidding of one wheel with respect to the other as the cause of the trouble. This skidding may be produced by unequal wheel diameters, due either to wear or to the use of coned wheel flanges, the intermittent effect of the skidding being increased by dust on the track rails.

REMOVAL OF CORRUGATIONS

37. **Methods of Grinding.**—Once corrugations have formed on a rail, the running of the cars becomes very unsatisfactory, the trucks being badly shaken, and the noise made by the cars such as to give rise to complaints from residents in the neighbourhood. The only way to deal with a corrugated rail is to grind the waves off its surface, and several forms of grinders are in use for this purpose. The first and simplest is formed by attaching a block of carborundum in a suitable manner to the frame of a car. The car is then run backwards and forwards over the rail with the block screwed

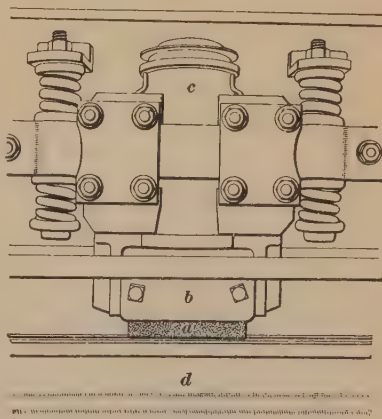


FIG. 24

hard down, and the corrugations are gradually reduced till the rail is perfectly smooth. In order to control the raising and lowering of the block, it is sometimes fitted to an electromagnet, the current from the trolley wire being switched on from the driver's platform, and the block let down where required. Fig. 24 shows an electromagnetic grinder attached to the car truck. The carborundum block *a* is clamped in the holder *b* and controlled by the electromagnet *c*. The block is shown in the operating position pressing on the rail *d*.

38. The second method in use is to have a special truck constructed and fitted with a motor driving carborundum wheels close to the rail tread, arrangements being made for lowering the grinding wheels as required. The truck is driven slowly over the route and the carborundum wheels are driven at a high rate of speed and adjusted to take the necessary amount off the tread. As the rails are corrugated, if the wheels of the grinding truck rested on them the unevenness would be reproduced at the grinding wheels, so the wheels are turned with specially deep flanges and run on the bottom of the groove of the rail, which is thoroughly cleaned out before the grinding commences. This type of grinder operates rather slowly for the removal of corrugations, but is very suitable for smoothing the rails where they are pounded at joints.

SPECIAL TRACK WORK

LAYOUT AND TYPES OF SPECIAL WORK

39. **Layout of Special Work.**—All roads have a number of crossings, curves, branch-offs, cross-overs, etc., and since these are different from straight track, in that they involve special care and precautions in their installation, they are all included under the general name of **special work**. Important special work is completed at the steelworks and sent ready to install.

As the construction of special work must be carried out with great accuracy, it is generally done step by step, and each stage of the work is carefully checked. The site of the special work

is first measured up and surveyed carefully, and a drawing is made of the proposed arrangement. This drawing is carefully checked, and is used as a means of laying out the work full size, with chalk, on a large smooth wooden floor. If the proposed method of construction is found to be satisfactory, the floor lines and angles are taken as guides for making wooden templates to be used by the patternmaker and the rail bender. When the separate parts of the job are complete, it is set up in the laying-out yard, where any slight errors are detected and rectified.

40. Types of Special Work.—A **plain curve**, in the sense that it is not complicated by any branch-offs, turnouts, or other special features, is shown in Fig. 25 (*a*). Such a curve can be simple or compound, single or double, right-hand or left-hand. A **left-hand branch** is shown at (*b*) and a **right-hand branch** at (*c*); these are used where a branch road leaves the main line. Facing the point of departure of the branch from the main line a right-hand branch turns to the right and a left-hand branch to the left. A **connecting curve and crossing** are shown at (*d*); the connecting curve in this case is a right-hand branch from the horizontal straight track and a left-hand branch from the vertical one. The diagram (*e*) shows a **plain Y**, (*f*) shows a **three-part Y**, and (*g*) a **through Y**; the three-part **Y** can be used instead of a loop to turn single-end cars at the end of the line. At (*h*) is shown a **reverse** or **S curve**, such as is often used where a cross-street is broken at the main street. At (*k*) is shown a **right-hand** and at (*l*) a **left-hand cross-over**, used to cross over from one track to the other; these are very convenient devices to place at intervals in a main line to turn cars back when they are disabled or when it is desirable to do so for other reasons. When it is practicable, a cross-over should be put in so that its switch points will lie in the direction of travel on the two tracks. A **diamond** or **Y turnout** is shown at (*m*), at (*n*) is an ordinary siding, or **side turnout**, and at (*o*) a **right-hand thrown-over turnout**, seen very often in temporary work, where it is of the nature of a temporary cross-over to avoid a gang of workmen. An interlacing line is shown at (*p*); this is used where a double-track construction comes to a narrow portion of the road.

If a single track were put in, spring points would be required,

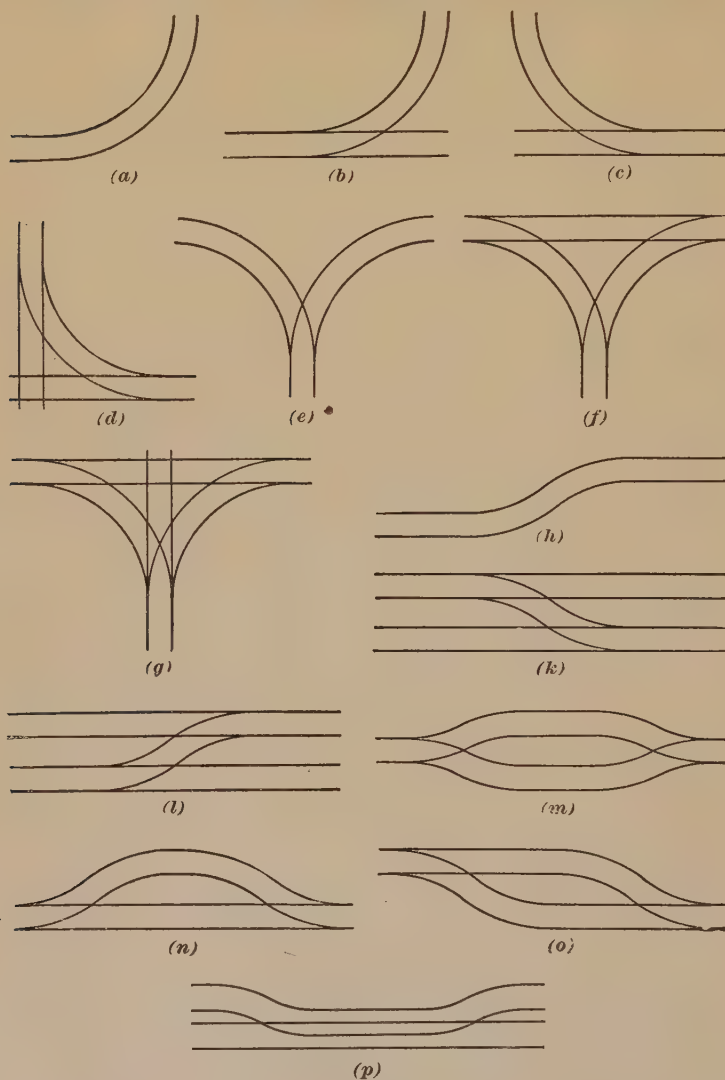


FIG. 25

and the wear on the single-track rails would be twice that on the adjacent double-track rails.

CURVES

41. **Kinds of Curves.**—Curves are of two kinds, *simple* and *compound*, or *transition*, curves. A *simple curve* is one that is described with only one radius throughout its length, while a *compound curve* is one so constructed that the radii become shorter as the middle point of the curve is approached from either end. A *compound curve* gives easier riding than a *simple curve*, because the direction in which the car is moving is changed more gradually.

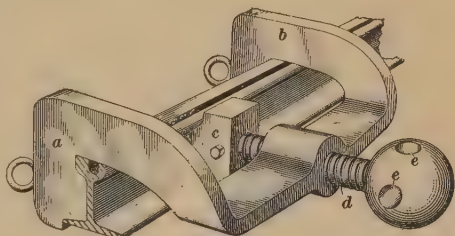


FIG. 26

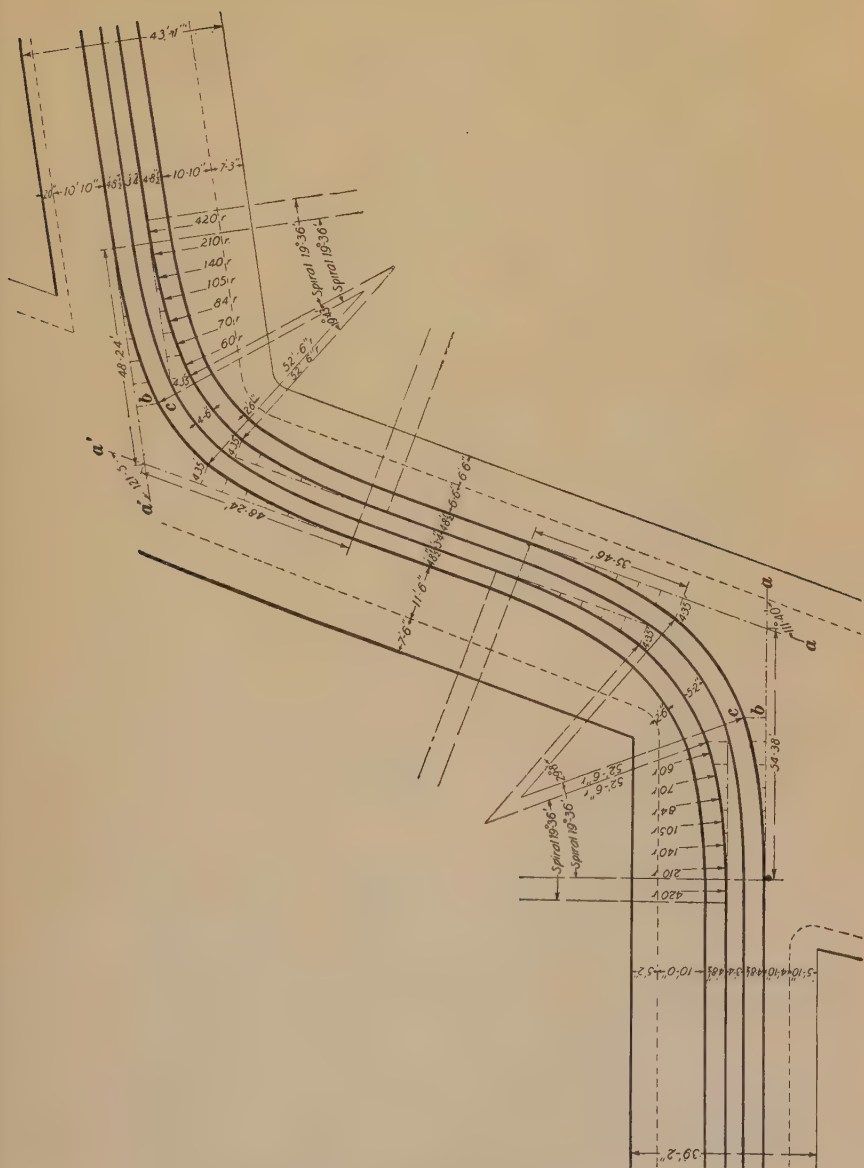
Tramway-track curves are always designated by the radius, in feet, at the centre. The rails are bent to the desired radius by means of a *rail bender* or *crow*, one type of which is shown in Fig. 26. The rail is supported by the arms *a* and *b*, and pressure is applied to the block *c* by means of the screw *d*, which is turned by means of a crow-bar inserted in the holes *e*. Both the arms and the block are shaped to take the full section of the rail, so that pressure is applied evenly to all parts of it, and twisting of the rail or crushing of the groove is avoided. For bending heavy rails, or in cases where there is a large amount of rail bending to be done, presses actuated by hydraulic pressure are employed.

42. **Considerations for Laying Out Curves.**—A very important point about laying out a single-track curve is to be certain that a car will go round it freely without either end striking any obstruction, and in the case of double track that the cars will clear one another. Whether or not two cars can pass each other on any given curve depends on the following: The length and width of the car; the amount by which the ends overhang the wheel base; the length of the wheel base; on double-track cars, the distance between trucks; the distance

between the track centres ; the amount of curvature of the track ; and the elevation of the outside rail. A good method is to lay out to scale on paper a plan of the proposed curve ; then, by means of a pasteboard dummy that scales the dimensions of the outside lines of the car, the actual clearance at all points can be readily determined. The positions of the car wheels may be indicated by holes through which the track can be seen, or transparent paper may be used, so that the dummy can be made to take the right path round the curve. Another point to be looked after in cutting out a dummy is to see that the widest part of the car is represented. To ensure some degree of safety to the heads and arms of passengers, the clearance on both sides of the car should be at least 15 inches, if cars are to pass each other on curves. Special attention must be paid to this feature where the centre-pole method of overhead construction is used.

43. Transition, or Compound, Curves.—By combining curves of different radii, a compound or transition curve is formed, such that the entrance of the car into the curve is gradual, and a sudden shock is avoided. The curve at the point where it branches from the straight part of the track, or a tangent, as it is called, is of long radius and the radii are gradually decreased until the radius of the centre of the curve is reached. Theoretically, the correct method would be to make a true spiral connection between the tangent and the centre of the curve, but this would be impracticable. Steel companies making a speciality of trackwork for electric tramways have developed standard transition curves that approximate to a spiral sufficiently closely for all practical purposes. For example, the Lorain standard curve for a radius at the centre of the curve varying from 40 feet to 62 feet 6 inches has an entrance radius of 432 feet.

At one time, curves for electric tramways were made up of arcs of different radii struck from three or five different centres, thus giving a rough approximation to a spiral. Curves as now used are made up of a number of radii such that the length of arc of any one radius is not over 5 feet. This gives a curve that is practically as smooth riding as a true spiral.



44. The principal dimensions of a compound reverse curve for a special case are given in Fig. 27. The angles between the straight tracks, or tangents to the curves are shown at a and a' , and a number of radii of the lengths indicated are used to construct arcs of about 5 feet in length which make up the curve. The position of the rail is checked by measuring the distance from the end of each arc to the tangent line, as shown by $b c$. The plan of the curve shows that the distance between the tracks is increased from 3 feet 4 inches to 4 feet 6 inches in one case and to 5 feet 2 inches in the other in order that the cars may pass on the curves. The minimum distance between the inner part of each curve and the kerb is 2 feet 6 inches.

45. **Construction of Special Work.**—In special track work, the greatest wear takes place at the points, which are subjected to the pounding action of the wheels caused by the breaks in the tread of the rail. On this account, points and crossings are now supplied either cast altogether in manganese steel or made of toughened cast steel and fitted with manganese-steel insert pieces at the wearing points. Fig. 28 (*a*) shows the latter type of point, the insert pieces being enclosed by the heavy lines. Each track is provided with two points, one of which is usually without a movable tongue, and is called a *fixed point*; the other is furnished with a tongue which is free to move, and is known as a *movable point*. Fig. 28 (*b*) shows the fixed point and Fig. 28 (*a*) the movable point, which turns about the part h .

The sections $a a$, $b b$, $c c$, $d d$, and $e e$ are those of the movable point, looking in the direction of arrow A . Section $f f$ shows the construction of the end h of the point. Section $g g$ is that of the fixed point, looking in the direction of arrow B . In some systems movable points are used on both rails. If the movable point is fitted with a spring to keep it closed always in one direction, it is called a *spring point*. This spring device is shown at section $e e$ in Fig. 28 (*a*). Such points are usually fitted at turnouts, so that cars passing in one direction are made to pass into the turnout, while cars passing in the other direction are made to keep to the main line. In passing the trailing points the wheel flanges force over the movable tongue.

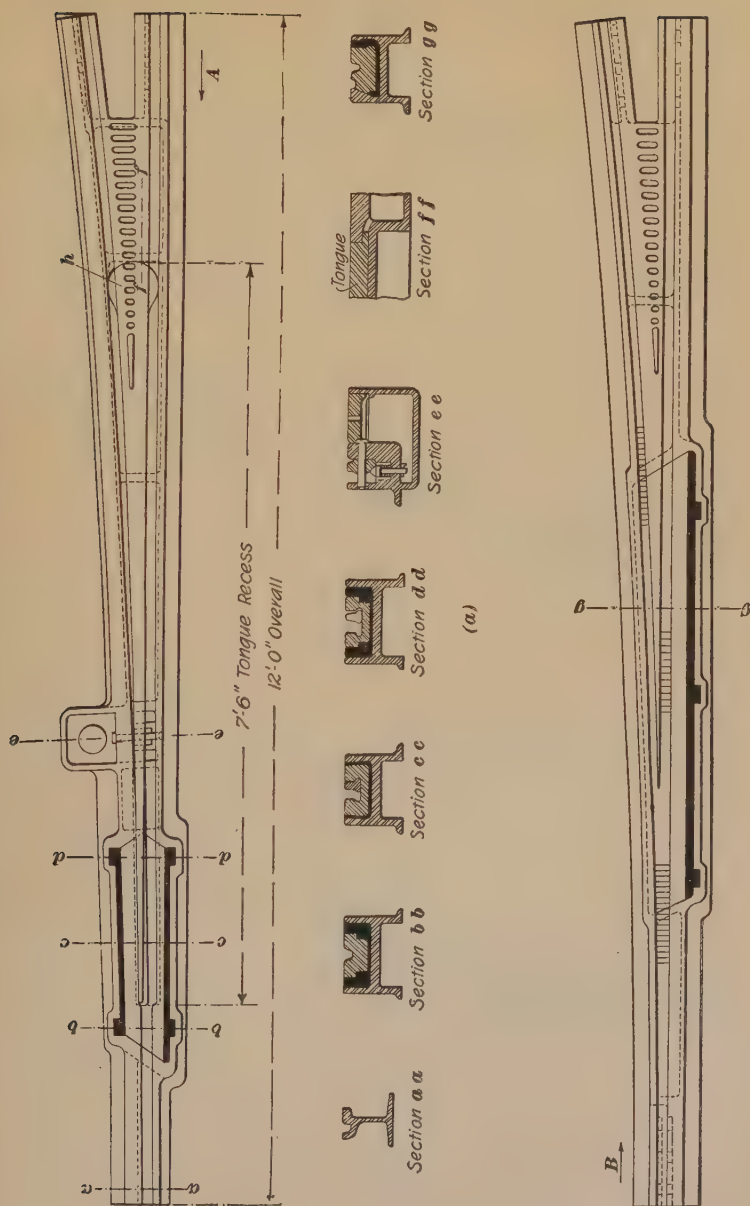


FIG. 28

46. A Hadfield manganese-steel point with a movable tongue *a* is shown in Fig. 29. The device for moving the tongue

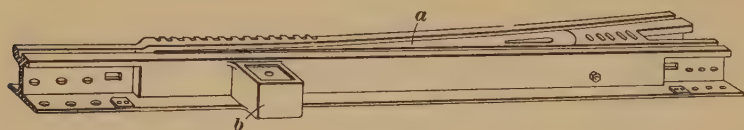


FIG. 29

is contained in the box *b*, and may consist of a spring or a bell-crank connection. These points are now usually supplied in

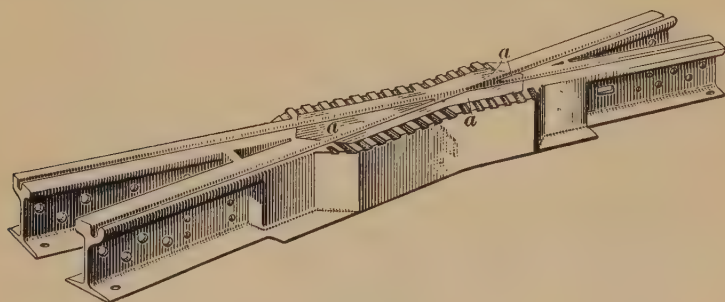


FIG. 30

lengths of from 9 to 12 feet ; they should be well drained by connecting them to the sewer or surface-water drain by means of 5-inch drain pipes. From the illustration it will be seen that

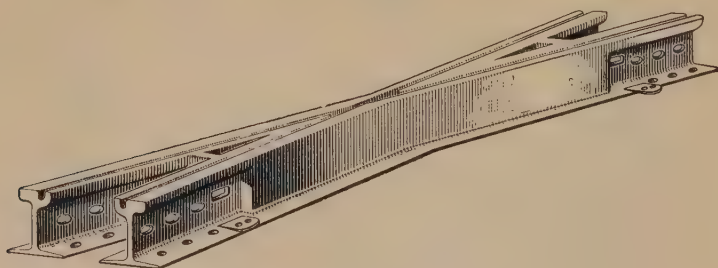


FIG. 31

the casting is finished off with a section the same as the section of the rail, so that the attachment to the rail can be made by means of fish-plates, as in an ordinary joint.

47. A cast-steel crossing provided with manganese-steel inserts *a* is shown in Fig. 30. The crossing shown in Fig. 31 is made of one piece of cast manganese steel.

The manganese steel used for these points and crossings is so hard that it cannot be drilled, though, if necessary, holes can be burnt by means of an electric arc. In general, however, the holes are cored in the rails when they are cast. Crossings are usually about 8 feet 6 inches long, and the angle is measured by the slope at the crossing. The usual angles are those corresponding to slopes of from 1 in 5 to 1 in 8.

48. The usual plan for a single-line turnout is shown in Fig. 32, and the arrangement of a standard cross-over for use

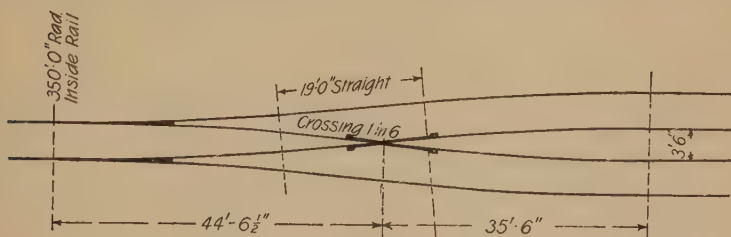


FIG. 32

with a double line in Fig. 33. The crossings that are required for use with the conduit system are very much more complicated and costly to make than those for the ordinary track, as the

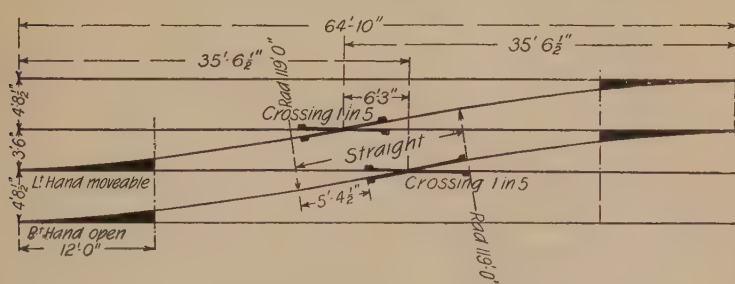


FIG. 33

central slot has to be held in place and the whole set supported over the duct. Fig. 34 shows a set of points and crossings for

a slot system, made by Hadfield's Steel Foundry Company, in course of erection at the maker's works.

The movable point *a* is sometimes known as a *tongue switch*, and the fixed point *b* as its *mate*. The use of the term switch in this connection is not to be recommended, however, as confusion is likely to ensue owing to the electrical use of the term.

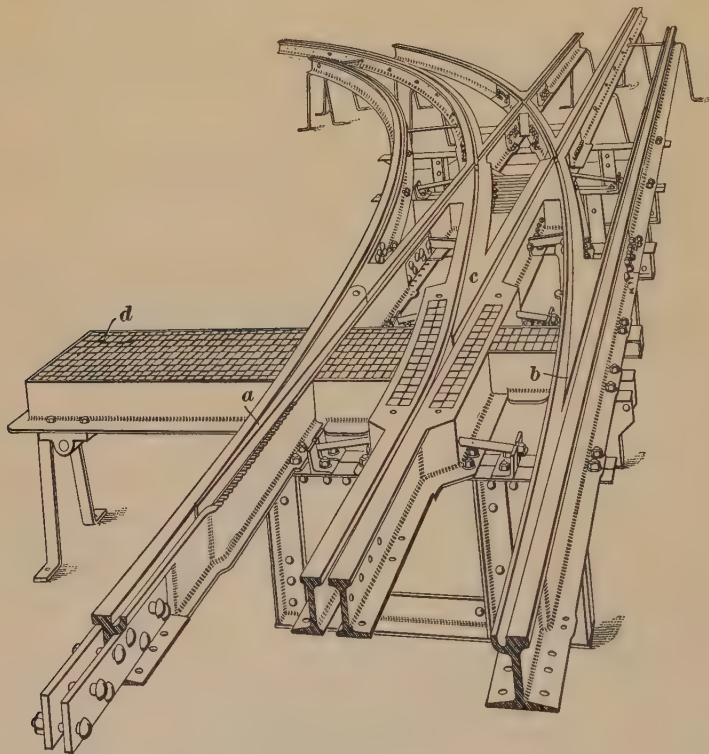


FIG. 34

The point for the conduit slot is shown at *c*, and both *a* and *c* are operated by means of a lever inserted in the slot *d*. If the special work is large, it is erected complete in a yard at the works instead of in the shops. By this method any inaccuracies in any part of the special work are discovered and can be remedied before the work is sent to the place where it is to be installed.

TRACK CONSTRUCTION AND PAVING

APPLICATION FOR PERMISSION TO CONSTRUCT TRAMWAYS

49. Procedure Necessary.—It is necessary for any corporation or company desiring to lay down a tram line to obtain permission to do so from either Parliament or the Light Railways Commissioners. Plans, showing the routes over which it is proposed to run cars, and the proposed position of the track on the roadway, must accompany the application for permission to construct the tramway. The plans must also show the lengths of single and double track, and the road widths and levels, any places where the rails for a distance of 30 feet or more are less than 9 feet 6 inches from the kerb line being marked as narrow places. These plans then form the working plans of the construction work so far as the position of the track is concerned.

In laying double track, it is not always possible to put both tracks down at the same time, owing to the necessity for keeping the road open for street traffic. In this case one track is completed first and thrown open for traffic while the other track is being constructed. Under the Tramways Act of 1870 the tramway authority must not, without the permission of the road authority, open at one time a greater length than 100 yards in any road which does not exceed $\frac{1}{4}$ mile in length, and in the case of any road exceeding this length a space of $\frac{1}{4}$ mile must be left between the openings. In no case is any part of the roadway to be left open for construction work for a greater period than 4 weeks.

PAVING

50. Types of Paving.—As the tramway authorities have to maintain the paving of the street between the outer rails and for a distance of 18 inches beyond the outer rails, the question of paving is a most important one. This maintenance is one of the hardships imposed on tramway authorities, who have thereby to pay for the cost of paving which is worn down by the ordinary street traffic.

The chief types of paving are (a) granite setts, (b) wood blocks, (c) macadam, (d) tar macadam, and (e) asphalt.

51. Size of Excavation.—The width of the excavation required for any of the types of paving depends on whether single or double track is used. For single track the width is as follows : Gauge of the track plus twice the width of the rail tread plus 36 inches, the last item being the two 18-inch strips of roadway outside the rails. For double track, the necessary width is double the gauge of the track plus 4 times the width of one rail tread plus the width between tracks plus 36 inches. The depth of the excavation will be the depth of the rail, usually $6\frac{1}{2}$ or 7 inches, plus the depth of the concrete foundation, which will not be less than 6 inches.

When a tram line is laid on country roads where, owing to the small amount of traffic, it is necessary to keep the construction costs as small as possible, the concrete is laid only underneath each rail. The usual width of concrete is 18 inches, so that the excavation necessary for a single track would be two trenches 18 inches wide and about 13 inches deep, and also narrow excavations from rail to rail for the tie-bars and electrical connections. In cold climates where the ground is frozen it is advisable to put in a sub-foundation of broken stone below the concrete. With light cars this method of construction is cheap and satisfactory. Where the lines run over private right of way, the rails may be carried on wooden sleepers, as in railway practice.

52. Track Paving With Granite Setts.—The most satisfactory paving, from the tramway engineer's point of view, is granite setts, as the wear on them is small. Fig. 35 shows the foundations and granite-sett paving for a single track. The concrete foundation, composed of 6 parts by measure of ballast to 1 of cement, is shown at *a* ; *b* is the bedding for the granite setts, consisting of cement mortar or sand and cement ; and *c* is the granite paving. After the excavation has been completed, the rails are placed in position, with all tie-bars, fish-plates, anchors, and electrical connections, if required. The rails are then levelled by packing them into position with wood packing pieces, and the concrete is laid and tamped firmly into position under

the rails. When the concrete has set, the bedding for the setts is laid, and the setts are placed in position and stamped down while the bedding is still soft. The paving is finished off by filling the interstices between the blocks for half their depth with

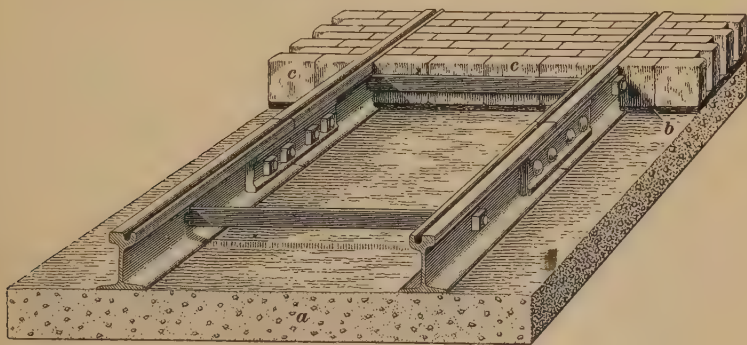


FIG. 35

bitumen and pitch oil, and completing the filling with cement. In some instances, the concrete foundation is put down first, and after it has set the rails are laid and levelled.

53. A section of a double track, which is lettered similarly to Fig. 35, is shown in Fig. 36. The cement filling, or *parging*, as it is called, that is used to fill the space between the rail web and the granite setts *c*, is shown at *d*. The curve, or camber, which is given to the surface of the road, in order that water shall flow to the gutters at the kerb, is also clearly shown.

54. Track Paving With Wood Blocks.—In some towns setts are objected to owing to the noise made by the street traffic in passing over them, and in order to reduce this noise wood blocks are put down. These blocks are sometimes made of soft wood thoroughly impregnated with creosote, but for tramway work the most satisfactory results have been obtained from blocks of a hard Australian wood, called *jarrah*. The blocks are commonly 9 inches long, $4\frac{1}{2}$ inches deep, and 3 inches wide, and are laid with the grain of the wood vertical. The concrete foundation of the track is covered over with a mixture of sharp sand and cement in the proportion of 2 to 1, and carefully surfaced up to give the



FIG. 36

right camber to the road. The blocks are often dipped in pitch before being placed in position, and are grouted from half to three-quarters of the way up with pitch or mastic asphalt, and finished off with a grouting of sand and cement. A special tie-bar is used, shaped as at *e*, Fig. 36, so as not to interfere with the paving blocks. With granite setts these special tie-bars are not necessary, as the bars can always be worked into the joints; in the case of close-fitting wood blocks, either the method shown would be adopted, or the blocks would be cut where necessary, to allow an ordinary tie-bar to be used. When wood blocks are used in a macadam roadway, it is difficult to make a satisfactory joint between the blocks and the macadam. One method which has been adopted is to lay the wood paving to a width of 14 inches beyond the outside rails, the remaining 4 inches of the margin being made up by granite setts 4 inches wide, laid edgewise. The most satisfactory method is to make the margin entirely of setts, the wood paving only being between the outside rails.

55. Track Paving on Macadam Roads.—As has been already mentioned, the rails in country districts are sometimes laid on a longitudinal sleeper of concrete to save the expense of excavating the whole width between the rails. The road is usually of macadam, and this is not disturbed more than the rail excavations necessitate. Macadam is the name applied to the ordinary road surface of broken stone and sand rolled smooth. To make a lasting joint between the rail and the macadam it is found advisable to place a row of granite setts on either side of the rail, the inside setts being laid longitudinally and the outside setts transversely, a long sett and a

short one alternately. This construction is shown in Fig. 37 (*a*) and (*b*), where the concrete foundation is lettered *a*, the granite setts *b*, and the macadam *c*.

56. Track Paving With Tar Macadam and Asphalt.—The paving material known as tar macadam has only recently been used. It consists of broken stone, or furnace slag, mixed with a tar compound ; this is laid and rolled like ordinary macadam.

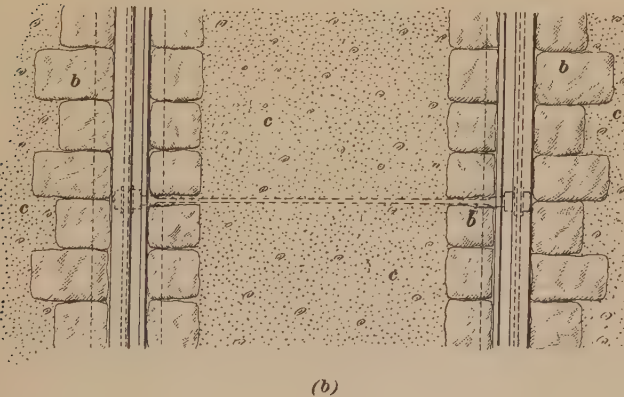
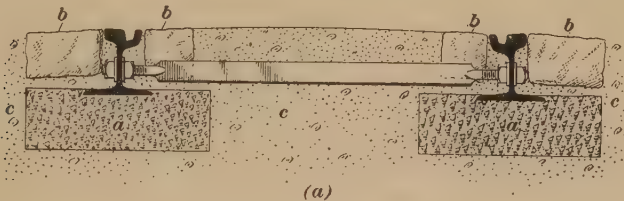


FIG. 37

Next to the track rails is laid a single course of granite setts in the same way as described in the preceding article. The advantage of tar macadam paving is the absence of dust.

Where asphalt paving is used on tramway tracks, the concrete is carried to within an inch of the rail-tread level and a thin layer of asphalt is rolled on top. This construction gives an exceedingly smooth and dust-free surface, but is only suitable where the road traffic is light.

ELECTRICAL CONSIDERATIONS

RESISTANCE OF TRACK AND CONDUCTOR RAILS

57. Resistance of Track Rails.—Since, in most electric railways, the track is used as one side of the circuit, it is important to know the electrical resistance of steel. The resistance of mild steel varies greatly with its composition; the harder the steel, the higher is the resistance. Track rails are selected for their wearing qualities; hence, a certain degree of hardness is essential; but where a rail is used simply as a working conductor, as in conduit systems, it can often be made of softer steel, because the only wear to which it is subjected is that of the collecting shoes.

Extended tests made on specimens of rails obtained from different sources show specific electrical resistances varying from 6.4 to 13.2 times that of copper. A fine grade of Swedish wrought iron showed a resistance of about 6 times that of copper.

In making calculations regarding track resistance, it has often been assumed that steel ordinarily used in track rails has a specific resistance of 7 times that of copper. Tests show, however, that in most cases the average specific resistance is much higher than this, a value of 10 times the resistance of copper being more nearly in accordance with the facts; this value will therefore be used in the ensuing formulæ.

58. Steel for Conductor Rails.—In cases where the cars are supplied with current from special conductor rails, as in conduit systems, the rails are generally rolled from special soft steel of higher conductivity than that used for the track rails, as mentioned before. Rails rolled from this special steel cost somewhat more than track rails, though tests show that, by properly limiting the impurities in the steel, there is no difficulty in securing a composition which can be made without greatly increasing the cost, and which will have a resistance of not more than 8 times that of copper. The element having the greatest effect on the resistance is manganese, and if the percentage of this is kept down, the other impurities can be present in a

considerable amount without causing a very high resistance. Chemically pure iron has a resistance approximately 4·5 times that of copper, and comparatively small percentages of impurities increase the resistance in a marked degree. Pure iron, even if it could be obtained at reasonable cost, would not be suitable for conductor rails, because it would not be hard enough to stand the wear of the collecting shoes. At the same time, if a conductor rail is made with percentages of carbon and manganese lower than ordinarily used, the conductivity can be improved. The following composition is recommended as giving a resistance not exceeding 8 times that of copper: Carbon not to exceed ·15 per cent.; manganese not to exceed ·30 per cent.; phosphorus not to exceed ·06 per cent.; sulphur not to exceed ·06 per cent.; and silicon not to exceed ·05 per cent.

59. Formulæ for Rail Resistance.—The resistance of 1 yard of copper 1 square inch in cross-section, at 25° C., is ·000025. The specific resistance of steel is taken as being 10 times that of copper.

The resistance of 1 yard of steel 1 square inch in cross-section is, from the foregoing, ·00025 ohm. The resistance varies inversely as the cross-section, and therefore inversely as the weight, as the cross-section, in square inches, is equivalent to the weight divided by 10.

Let R_y = resistance, in ohms, per yard of rail;
 W_y = weight of rail, in pounds, per yard.

$$\text{Then, } R_y = \frac{\cdot 00025}{\frac{W_y}{10}} = \frac{\cdot 0025}{W_y} \quad (1)$$

Rule I.—*The resistance, in ohms, of 1 yard of steel rail is equal to ·0025 divided by the weight, in pounds, per yard.*

Sometimes it is more convenient to have the resistance expressed in terms of 1,000 feet of rail. Since 1,000 feet = $\frac{1000}{3}$ yards,

$$R_l = \frac{\cdot 0025 \times \frac{1000}{3}}{W_y} = \frac{\cdot 833}{W_y} \quad (2)$$

Rule II.—*The resistance, in ohms, per 1,000 feet of steel rail is equal to ·833 divided by the weight, in pounds, per yard.*

If the resistance per mile is desired, the formula becomes

$$R_m = \frac{.0025 \times 1,760}{W_y} = \frac{4.4}{W_y} \quad (3)$$

Rule III.—*The resistance, in ohms, per mile of steel rail is equal to 4.4 divided by the weight, in pounds, per yard.*

60. In the case of a single track, there are two rails in parallel; hence, the resistance for each unit length of track, two rails, will be one-half that given by the preceding formulæ. For a double-track road, four rails in parallel, the resistance would be one-fourth that given by the formulæ.

With a track well jointed there is no reason why the resistance of 3 feet of rail including a joint should not be as low as that of 3 feet of the solid rail. Hence, for first-class construction, it is permissible to take the resistance calculated from the above formulæ as representing the actual track resistance, without the necessity of adding anything for extra resistance due to joints. If provision is not made for good connection at the joints, the values given by the formulæ will be exceeded by an amount depending on the resistance of the joints.

EXAMPLE.—Calculate the resistance of a 3-mile length of single track consisting of two rails in parallel, each weighing 100 pounds per yard.

SOLUTION.—The resistance may be found from formula 3, Art. 59.

$W_y = 100$; hence, $R_m = \frac{4.4}{100} = .044$ ohm, and the resistance of 3 mi.

of single rail will be $.044 \times 3 = .132$ ohm. The two rails being in parallel, the resistance of the track will be $.132 \div 2 = .066$ ohm. Ans.

61. For a special conductor rail, with a resistance 8 times that of copper, the formulæ become

$$R_y = \frac{.002}{W_y} \quad (1)$$

$$R_t = \frac{.666}{W_y} \quad (2)$$

$$R_m = \frac{3.52}{W_y} \quad (3)$$

These formulæ may be used for calculating the resistance of supply and return conductor rails, but will give results too small for ordinary track rails.

RESISTANCE OF WELDED JOINTS

62. **Resistance of Cast-Welded Joints.**—The resistance of the Falk cast-welded joint compared with that of an equal length of solid rail depends to some extent on the amount of iron used. In some cases the joint resistance may be somewhat higher than that of a corresponding length of solid rail, while in others numerous tests have shown that the resistance is as low or even lower, than that of the rail. The comparative resistances of 3 feet of rail with and without joints, and the number of feet of solid rail having the same resistance as the joint itself, are given in Table VI for a rail weighing 85 pounds per yard.

TABLE VI
RESISTANCE OF CAST-WELDED RAIL JOINTS

Joint Number	Resistance of 3 Feet of Rail Containing Joint Ohm	Resistance of 3 Feet of Solid Rail Ohm	Number of Feet of Solid Rail Having the Same Resistance as Joint Itself
1	·0000468	·0000451	·11307
2	·0000411	·0000239	2·15981
3	·0000275	·0000251	·28686
4	·0000307	·0000306	·00981
5	·0000342	·0000297	·45456
6	·0000291	·0000308	— 16557
7	·0000342	·0000306	·35295
8	·0000306	·0000231	·97404

The average of the values for the equivalent lengths of rail given in the last column of the preceding table is ·52319 foot, or ·5232 foot, approximately. By using this average value for the length of rail having a resistance equal to that of a joint, the equivalent length of solid rail may be calculated.

Let l = length of rail, in feet ;
 n = number of joints ;
 l_e = equivalent length of solid rail.

Then, $l_e = l + \cdot 5232 n$

If the equivalent length is known, the resistance may be determined by means of one of the formulæ of Art. 59.

63. Resistance of Electrically Welded Joints.—Tests show that the resistance of a length of rail with an electrically welded joint is generally considerably less than that of an equal length of solid rail. Table VII shows the resistances of 3 feet of rail with and without joints, and also the length of rail having the same resistance as the joint. The rail considered has a weight of 67 pounds per yard.

TABLE VII
RESISTANCE OF ELECTRICALLY WELDED RAIL JOINTS

Joint Number	Resistance of 3 Feet of Rail Containing Joint Ohm	Resistance of 3 Feet of Solid Rail Ohm	Number of Feet of Solid Rail Having the Same Resistance as Joint Itself
1	·00002966	·00004081	—·81963
2	·00002916	·00003927	—·77232
3	·00003111	·00004076	—·71025
4	·00002971	·00003583	—·51243
5	·00002850	·00002621	—·63876
6	·00002893	·00004071	—·86808
7	·00002748	·00003671	—·75429
8	·00003251	·00003951	—·53151

As the resistance of a length of rail including a joint is less than an equal length without a joint, the resistance of the joint itself is equal to a negative length of rail, and therefore the minus sign is used in the table. The average of the values given is —·7009 feet; this means that the equivalent length of rail is reduced by ·7009 feet for every joint it contains. Then, for electrically welded joints, the formula given in Art. 62 becomes

$$l_e = l - \cdot 7009 n$$

64. Resistance of Thermit-Welded Joints.—The resistance of the thermit joint depends, as does that of the cast-welded joint,

on the amount of iron used in the weld. The resistances of 3 feet of rail with and without thermit joints are shown in Table VIII for a rail weighing 80 pounds per yard, from which it will be seen that the resistance of the rail with the joint is somewhat higher than that of the solid rail.

TABLE VIII
RESISTANCE OF THERMIT-WELDED RAIL JOINTS

Joint Number	Resistance of 3 Feet of Rail Containing Joint Ohm	Resistance of 3 Feet of Solid Rail Ohm	Number of Feet of Solid Rail Having the Same Resistance as Joint Itself
1	·0000356	·0000321	·32712
2	·0000347	·0000293	·55293
3	·0000377	·0000316	·57912
4	·0000369	·0000292	·79107
5	·0000365	·0000276	·96741
6	·0000306	·0000311	—·04821
7	·0000359	·0000266	1·04889

The average of the values in the last column of the table is ·6026 foot, approximately. As in the previous case, the equivalent length may be determined by adding a length to the measured length of rail to make up for the resistance of the joints. Using the average given in the table, the formula given in Art. 62 becomes, for thermit-welded joints,

$$l_e = l + \cdot 6026 n$$

RAIL BONDS

65. Necessity for Bonds.—When the track rails are used to carry the return current and are joined by means of ordinary fish-plates, these must be supplemented by connections, usually of copper, called **rail bonds**, that will carry the current from rail to rail. These rail bonds consist of copper conductors attached to the rails on each side of a joint in such a manner as to make

a very good contact. The fish-plates cannot be depended on to carry the current, because they soon become loose or rusty and offer a high resistance. Joints of the cast-welded or thermit types are also often bonded, in order to ensure electrical continuity of the rail in case of failure of the joint. A great many varieties of rail bond are in use, so that it will be possible to describe here only a few typical examples. No matter what type is used, it must always be remembered that, if a joint is mechanically poor, the continual movement and pounding will sooner or later decrease the efficiency of the bond. It is highly important, therefore, that the joints be kept in good condition. If a track is poorly bonded, there will be a continual loss of power due to the resistance at the joints, the voltage supplied to the car motors will be low, and the speed will be correspondingly reduced. Also, if the return circuit is poor, current will come back to the generating station through neighbouring pipes instead of through the track rails, and trouble on account of electrolysis will result. The maximum drop of voltage allowed by the Board of Trade is, on this account, limited to 7 volts. Bonds are also used for connecting up conductor rails in conduit systems and on electric railways.

66. Classification of Bonds.—Rail bonds may, for convenience, be divided into two general classes: *protected* and *unprotected*.

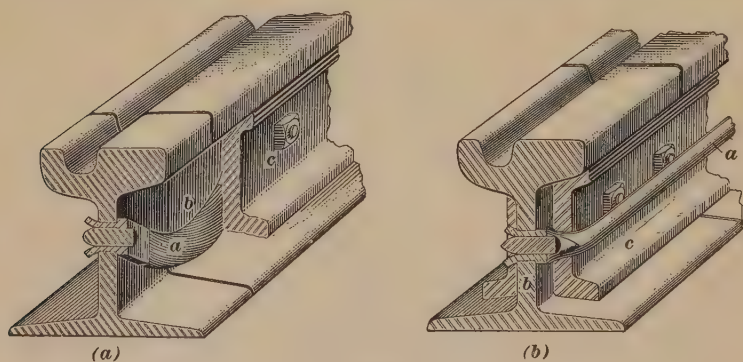


FIG. 38

Protected bonds are so called because they are placed in the space between the fish-plate and the web of the rail, as shown in

Fig. 38 (*a*), where the bond *a* is attached to the rail web *b* on both sides of the joint and protected by the fish-plate *c*. Unprotected bonds span the fish-plate, as shown in Fig. 38 (*b*), where the bond *a* is connected to the web *b* on each side of the fish-plate *c*.

67. Construction and Method of Connecting Bonds.—Bonds of the protected type are used in cases where there is sufficient space for them between the fish-plate and the rail web, as they may be made considerably shorter, and therefore less expensive, than the unprotected type; on the other hand, bonds that are less than 6 inches in length are more liable to give trouble from breakage than longer bonds. The method of making contact between the bond and the web of the rail is a matter requiring careful consideration, and many methods are in use. It is essential that

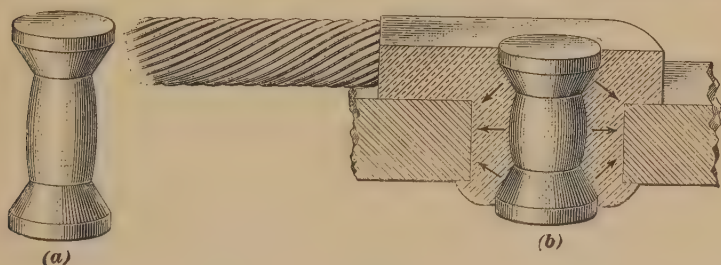


FIG. 39

there shall be no possibility of corrosion due to moisture between the terminal and the rail, and that vibration shall not be able to loosen the connection. The bond shown in Fig. 39 (*a*) and (*b*) is made by casting copper terminals on a stranded copper conductor. The copper is cast round an iron plug of the form shown in Fig. 39 (*a*), and after the terminal has been fitted in the web of the rail, the plug is compressed to the form shown in (*b*), thus forcing the metal out against the wall of the hole, as indicated by the arrows, and providing a very firm contact between the terminal and rail. Bonds consisting of thin copper strips soldered together at the ends so as to form solid terminals, which are attached to the rail by soldering, have been experimented with, but are unsatisfactory, as they corrode when they are in contact with damp earth.

68. A protected bond of the *double-loop type*, shaped so as to give flexibility and at the same time allow openings for the fish-

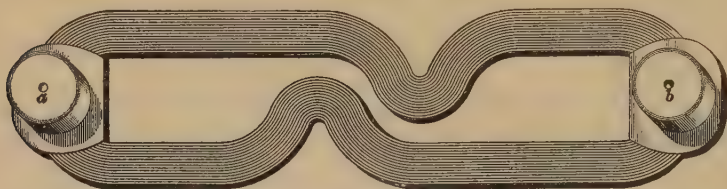


FIG. 40

plate bolts, is shown in Fig. 40. The bond is made of thin copper strips on which copper terminals *a*, *b* have been cast. After these

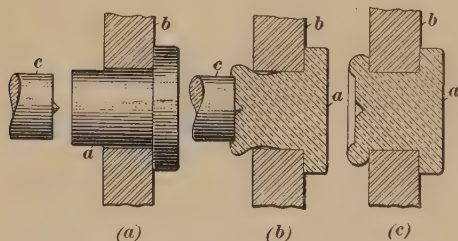


FIG. 41

terminals have been passed through the holes in the rail web, they are compressed by a special screw compressor that forces the metal out sideways, as shown in Fig. 41 (*a*), (*b*), and (*c*). In view (*a*) the copper terminal *a* is shown in position in the rail web *b*, one jaw of the screw compressor being shown at *c*. In view (*b*), the terminal *a* is shown half compressed, and it will be seen that the copper of the terminal is being forced outwards into contact with the steel of the rail web *b*. View (*c*) shows the completed contact; the terminal *a* completely fills the hole in the web *b*, and also forms a flange which holds the bond firmly in position.

69. The construction of the screw compressor used for expanding the copper terminals into intimate contact with the rail web is shown in Fig. 42. The compressor consists of a strong steel frame *a* furnished with a screwed steel tube *b*, which can be turned, and thus caused to travel backwards or forwards through the boss *c* of the frame, by means of the hand wheel *d* and nut *e*. The inside of the tube *b* is also provided with a screw thread, in which runs a screwed steel rod, one end *f* of

which carries a point and is used for expanding the terminals, and the other end is furnished with a square head *g*, in order that the whole rod may be screwed forwards by means of a wrench. When fixing the bond, the hole in the rail web is made thoroughly clean and bright by means of a round file or a reamer, and the bond terminal is also made clean and bright. The terminal is then inserted in the rail web, and the compressor placed over the rail and bond with the jaw *h* against the flat part of the bond. The inner screw is then run forwards until the point of the rod strikes into the indenture in

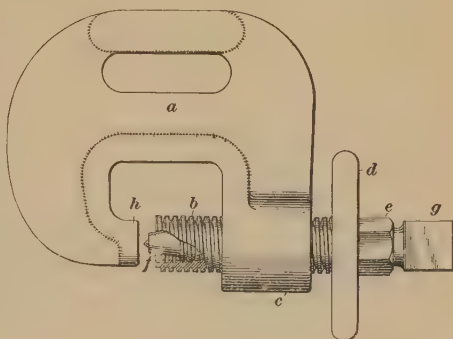


FIG. 42

the end or face of the terminal; this centres the machine and ensures a uniform pressure on the terminal. The outer screw is next drawn up with the hand wheel until it reaches the rail web and is firmly set by means of the wrench, thus holding the compressor rigidly and drawing the bond home. The inner screw is then moved forwards with the wrench to compress the terminal, the forward movement being continued until the terminal is as shown in Fig. 41 (*c*).

70. Another type of rail bond which is much used for all classes of work is shown in Fig. 43, the flexible protected type being shown in view (*a*), and the solid unprotected type, for spanning over the fish-plate, in view (*b*). These bonds are connected to the rail in the following way: The holes in the rails and bond terminals are made thoroughly clean and bright. The terminal is then inserted in the hole in the rail web, and the lower end is spread over on the rail with a hammer and punch. A steel pin is then driven into the hole in the bond, expanding the metal of the terminal into good contact with the rail web. The completed joint is shown in Fig. 43 (*a*), in which *a* is the

rail web, *b* the bond terminal spread over by the punch at *c*, and *d* is the steel pin. This type of bond is made in a great variety of shapes suitable for all purposes.

71. Electrically Welded Bonds.—An exceedingly quick and effectual method of attaching bonds to the rails has been brought out by the Forest City Electric Company. This consists in welding the ends of the bond to the rail by means of an alternating current of about 2,000 amperes at a pressure of 5 volts. The current is obtained by taking about 23 amperes, direct current, at 500 volts, from the trolley wire and converting it to alternating current at the required pressure by passing it

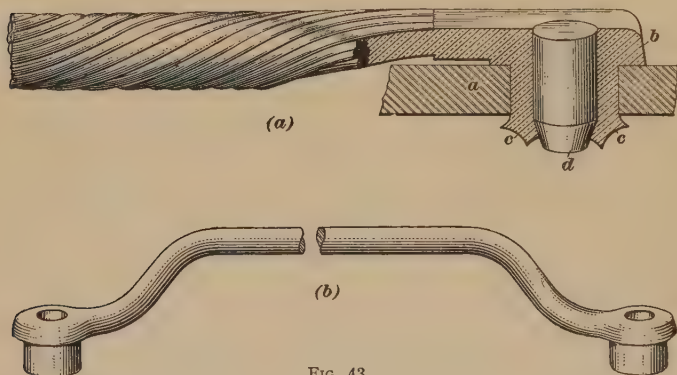


FIG. 43

through a rotary converter and transformer. The equipment somewhat resembles that used for electrical rail welding, but as the current required for bond welding is so much smaller, the transformer and clamping terminals are separate, one transformer usually supplying two sets of clamping terminals.

72. The appearance of the clamping device in position for making a weld is shown in Fig. 44. The two clamp terminals are shown at *a* and *b*, the terminal *a* being merely a copper block and terminal *b* carrying a block of carbon *c*. When in position, terminal *a* makes contact with the rail web, and the end of the bond *d* is held against the other side of the rail web by the carbon block *c*. The current is conveyed to the terminals by

the heavy cables *e, e*, and the pressure on the terminals is controlled by the screw handles *f, f*. When the current is turned on, it passes from one terminal to the other by way of the bond and rail, making the carbon block *c* incandescent. The combination of the great current density at the surface of the web of the rail where it is in contact with the bond terminal, and the incandescent carbon pressing the copper bond terminal against this surface, quickly generates sufficient heat at exactly the point where it is required to produce a weld. The time required to make a weld is from 45 to 60 seconds, depending on conditions. With bonds of this type there is no danger of the contact deteriorating through corrosion, and the operation of bonding can be performed quickly. It is essential, however, that both sides of the rail web and the bond terminal should be clean and bright before the bond is placed in position. The same company also supply outfits for welding bonds by pouring molten copper over the contact point of bond and rail, but this method is more difficult to carry out than the electrical one.

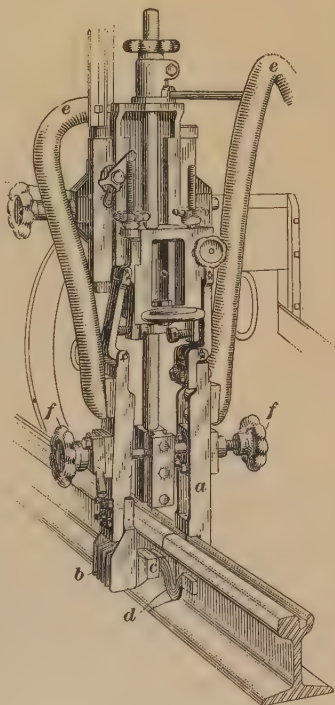


FIG. 44

73. Plastic Bonds.—A type of bond which has been used to some extent in America is known as the **plastic bond**. It consists of solid plates of metal pressed firmly against the rail web, the contact surfaces being first thoroughly cleaned and coated with copper-mercury amalgam of about the consistency of putty, which adheres to the surfaces and makes a connection of very

low resistance. In some forms of this bond the plates are made of copper, and in others the fish-plates themselves are used when they are of sufficient cross-section to carry the current. A bond of the plastic type is shown in Fig. 45 (a). The plastic amalgam *a* is held in a cork case, which is compressed when the fish-plates are bolted together, thus bringing the amalgam into intimate contact with the rail and plate surfaces, which have previously been ground off and amalgamated. The path of the current through the joint is indicated in view (b). In all of these amalgamated

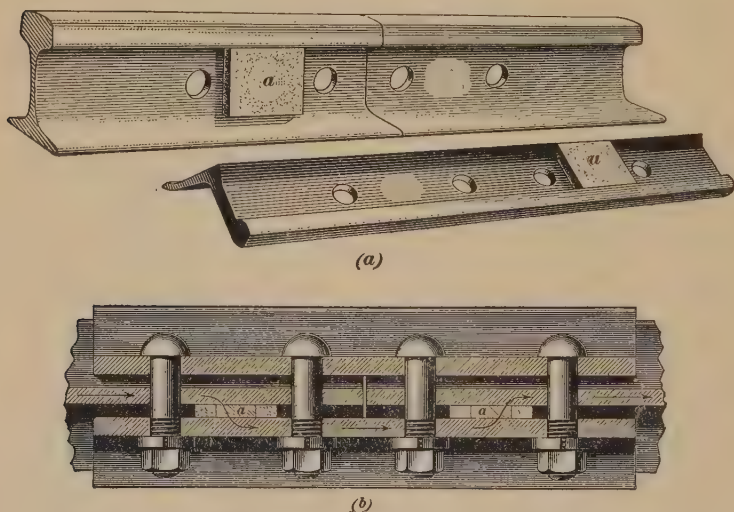


FIG. 45

bonds a slight movement between bond and rail does not impair the contact ; in fact, the amalgam acts, to a certain extent, as a lubricant.

74. Resistance of Bonds.—In making track joints, the aim should be to keep the electrical resistance measured from terminal to terminal of the bond at least as low as the resistance of a corresponding length of rail. It is not difficult to do this with a new joint, but the constant jarring and slight movements to which the bonds are subjected will often cause an increase in resistance when the bonds are not of the welded type. It should

be noted that in Great Britain the sizes of wire bonds are given in Brown & Sharpe gauge (abbreviated B. & S.), and not in Standard wire gauge.

The bond holes in the rail web are usually made of smaller diameter than they are ultimately intended to be, so that they can be reamed out to size immediately before the insertion of the bonds, thus ensuring a clean contact surface. The sectional

TABLE IX
SIZES OF BOND WIRES

Size of Wire, Brown & Sharpe Gauge	Sectional Area of Bond Wire Square Inch	Diameter of Terminal and Hole in Rail Web Inch
0000	·1662	$\frac{7}{8}$
000	·1318	$\frac{3}{4}$
00	·1045	$\frac{5}{8}$
0	·0829	$\frac{1}{2}$

areas of the Brown & Sharpe wires for bonds, and the usual sizes of terminals and holes in the rail web, are given in Table IX.

75. A No. 000 B. & S. wire has a cross-section of ·1318 square inch, which, assuming the specific resistance of steel to be 10 times that of copper, is equivalent to 1·318 square inches of steel. Two bonds, each 1 foot long, in parallel connecting two 90-pound rails (9 square inches cross-section) will have a resistance equal to that

of $\frac{1}{2} \times \frac{9}{1.318} = 3.41$ feet of rail, neglecting resistance at the

bond contacts. The total resistance of a joint is the resistance of the bond in parallel with the resistance that the joint would have without any bond. The channel plates or fish-plates provide some conductivity, but it is very uncertain owing to the variable nature of the contacts between plates and rail. If the work is done carefully, the resistance as measured across 3 feet of rail including the fish-plates and bond can be kept quite as low as the resistance of 3 feet of solid rail. It is necessary, of course, to proportion the bonding according to the weight of the rail; for example, a 110-pound rail should be bonded heavier than a 90-pound, either by using a heavier bond connection or by providing more bonds at each joint.

TABLE X

LENGTHS OF RAIL EQUAL IN RESISTANCE TO BOND 1 FOOT LONG

British Standard Rail Section Number	Weight of Rail Pounds Per Yard	Cross- Section Square Inches	Cross-Section of Copper Equivalent in Conductivity to Rail Square Inch	Feet of Rail Equal in Resistance to Bond 1 Foot Long Assuming Resistance of Steel = 10 × Resistance of Copper							
				Single No. 0000 B. & S.	Two No. 0000 B. & S. in Parallel	Single No. 000 B. & S.	Two No. 000 B. & S. in Parallel	Single No. 00 B. & S.	Two No. 00 B. & S. in Parallel	Single No. 0 B. & S.	Two No. 0 B. & S. in Parallel
1	90	9	·9	5·41	2·71	6·83	3·41	8·61	4·31	10·86	5·43
1c	96	9·6	·96	5·78	2·89	7·28	3·64	9·19	4·6	11·58	5·79
2	95	9·5	·95	5·72	2·86	7·21	3·61	9·09	4·55	11·46	5·73
2c	101	10·1	·101	6·08	3·04	7·66	3·84	9·67	4·84	12·18	6·09
3	100	10·0	·100	6·02	3·01	7·59	3·9	9·57	4·79	12·06	6·03
3c	106	10·6	·106	6·38	3·19	8·04	4·02	10·14	5·07	12·79	6·40
4	105	10·5	·105	6·32	3·16	7·97	3·99	10·05	5·03	12·67	6·34
4c	111	11·1	·111	6·68	3·34	8·42	4·21	10·62	5·31	13·39	6·70
5	110	11·0	·110	6·62	3·31	8·35	4·18	10·53	5·27	13·27	6·64
5c	116	11·6	·116	6·98	3·49	8·80	4·40	11·10	5·55	13·99	7·00

Table X shows the lengths of rail that are equal in resistance to wire bonds of various sizes, Brown & Sharpe gauge, 1 foot long. Thus, if a 95-pound rail is bonded with two No. 0000 bonds, each 1 foot long, the resistance of the bonds is equal to that of 2.86 feet of rail, assuming that the resistance between bonds and rail is negligible and that the specific resistance of steel is 10 times that of copper.

76. Cross-Bonding.—It is necessary to cross-bond or connect the two rails of the track together at certain intervals so that a break in one or more joints may not seriously impair the conductivity of the return circuit. For example, consider a single-track road where the two rails are bonded throughout but not connected to each other. If a break occurs at a given joint, the portion beyond the joint is of no use in aiding as a return for the current, and an additional load is thrown on the other rail. If, however, the rails are cross-connected at intervals, the current can flow round the break and only a small section of the rail is cut out. On double-track roads all four rails should be connected together. Cross-bonding, with No. 0000 B. & S. copper, should be provided every 40 yards between the rails of one track, and every 80 yards between tracks.

Ordinary bonds in special work, such as points and crossings, are liable to work loose owing to the pounding, so that long bonds should be carried round such fittings from rail to rail, in addition to the short bonds between the fittings and the rail.

BOND TESTING

77. Comparative Tests.—No matter how well a track may be bonded, tests should be made frequently to see that the bonds are in good condition. This is especially necessary round special work and where low joints are noticed. It is not necessary to measure the actual resistance of each joint; comparative readings only are required. For a given class of bonding, the resistance of a joint in good condition as compared with a certain length of rail is known, and it is only necessary to measure the resistance of the joint in terms of rail length; any joints

showing an abnormally high resistance can then be investigated. Usually, 3 feet of rail is taken as the standard, and the resistance, measured between two points 18 inches on either side of the joint, is compared with that of 3 feet of rail. For example, the bonding may be such that a joint in good condition has a resistance perhaps slightly over that of 3 feet of rail, and if a test showed that the resistance was more than twice that of 3 feet of rail, the bonding would be considered poor.

78. Drop-of-Potential Test.—The simplest method of testing for poor bonds is by measuring the drop across the joint by means of a millivoltmeter, and comparing this measurement with the drop across 3 feet of rail. If the current has the same value both in the joint and in the length of rail, the resistances are directly proportional to the voltmeter readings. Owing to the low value of the resistances to be measured, it is necessary to use a low-reading voltmeter, such as a millivoltmeter, to get readings with a reasonably small current in the rails.

Let E_j = drop across 1 yard of rail including joint, in millivolts ;

E_r = drop across 1 yard of solid rail, in millivolts ;

R_j = resistance of 1 yard of rail and joint, in ohms ;

R_r = resistance of 1 yard of solid rail, in ohms.

Then,
$$\frac{E_j}{E_r} = \frac{R_j}{R_r}$$

Thus, in order to determine the ratio of the resistance of a length of rail including a joint to the resistance of an equal length of solid rail, it is only necessary to find the ratio of the millivoltmeter readings in the two cases, care being taken that the current flowing is constant in value.

79. Siemens Bond Tester.—It is usually necessary to make tests of bonds while cars are actually in operation on the system. In this case the current returning along the rails from the cars produces the voltage drop. It would not be satisfactory, however, to take the drop across the joint and then that across 3 feet of rail, because the current in the rail varies as cars are started and stopped, and might not be the same for the two readings. One method of overcoming this difficulty, used in the

Siemens rail-joint tester, is to use a differential millivoltmeter.

This is an instrument provided with two windings such that, when equal potentials are applied to the terminals of each, the instrument gives no deflection. One of the windings is connected across the joint, and the other across a length of solid rail. The connections and principle of operation of this device are shown in Fig. 46. The contacts *a* and *b*, which in practice consist of sharp

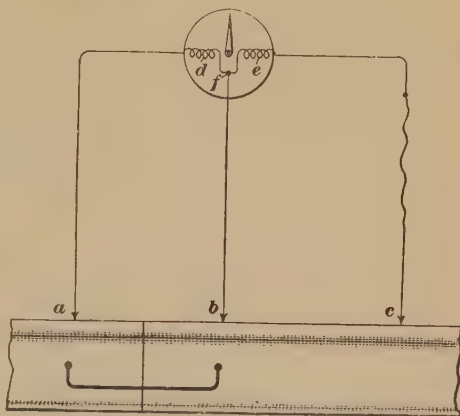


FIG. 46

steel knife-edges, are adjusted and fixed so that the distance between them is approximately equal to the length of a bond. The contact *c*, which is also a steel knife-edge, is movable. Contacts *a* and *b* are connected to one winding *d* of the differential millivoltmeter, the other winding *e* of which is connected across the contacts *b* and *c*. The two windings are joined at *f*.

80. If, with connections as shown in Fig. 46, the position of the contact *c* is adjusted until the millivoltmeter reads zero, it follows that the drop of potential across *a b* is equal to that across *b c*, or, in other words, the resistance of the rail and joint between *a* and *b* is equal to that of the length of solid rail between *b* and *c*. The position of the point *c* at which zero reading is obtained is quite unaffected by fluctuations in the current flowing in the rail, because the potentials across *d* and *e* are equally affected by any change in current. This method of working gives the equivalent resistance of the joint, in feet of solid rail. If the actual resistance of the joint is required, it can be approximately calculated if the resistance per foot of the solid rail is known. Where a large number of joints are to be tested, the apparatus required for testing is sometimes

installed on a car, which is driven slowly over the track, the tests being made while the car is in motion, and bad joints marked by dropping whitewash on the track.

81. Telephonic Bond Tester.—The method of testing in which a telephone receiver is employed as a detector differs somewhat in principle from the method just described, and possesses the advantage that it can be operated by one person. Fig. 47 shows the method of using the instrument. A bar is provided with

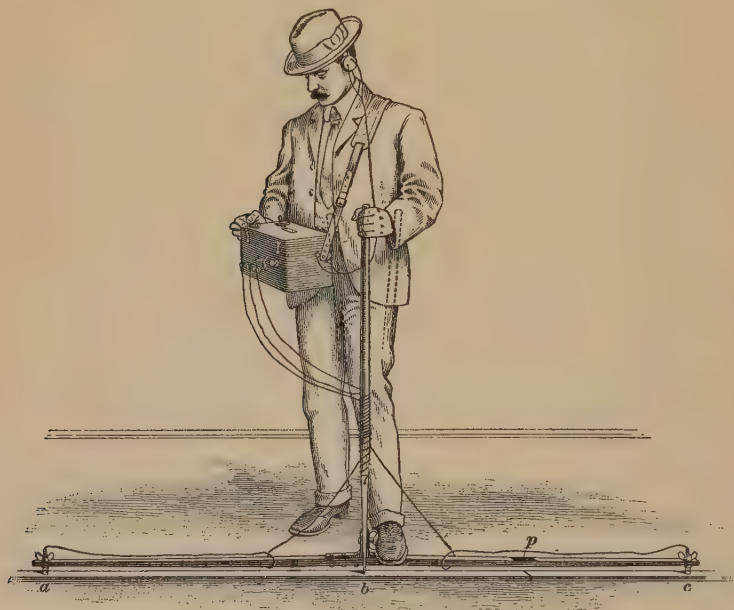


FIG. 47

three hardened-steel knife-edge contacts *a*, *b*, *c*, and a handle at right angles to the bar. When the bar is placed on the rail, as shown, contacts *b*, *c* span 3 feet of rail including the rail joint, plate *p* being placed over the joint, and *a*, *b* span 3 feet of solid rail. The bar is made of tough springy wood, and when the two end contacts rest on the rail, the centre contact is a short distance above the rail, and is pressed down by placing a foot on the bar, as shown. This forces the end contacts out slightly,

and causes the hardened chisel-like contacts to cut through any scale or dirt that may be on the rail, thus making a good connection. In order to make sure that the contact is good, the centre handle can be moved backwards and forwards, as indicated by the dotted lines; the contacts must be sharpened occasionally by means of a small oilstone.

82. The operation of the instrument will be explained by reference to Fig. 48, where a , b , c represent the

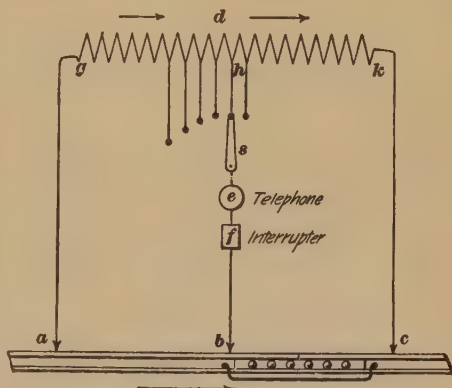


FIG. 48

three contacts on the rail; d is a resistance to which the central contact can be connected at various points by means of a multi-point switch s . In series with the middle wire is included a telephone receiver e and an interrupter f , consisting of a clock-work mechanism that drives a toothed contact wheel, on which presses a small contact spring.

The rail current is represented in Fig. 48 by the heavy arrow; it will be the same in the section of rail ab and in the joint bc , and will fluctuate according to the number of cars taking current beyond the joint. Resistance d being shunted across the rail and joint, part of the current will flow as shown by the small arrows. If the rail section ab is equal in resistance to the joint bc , and if switch s is so placed that resistance gh is equal to hk , there will be no current in the middle wire and no sound in the telephone, because points h and b will be at the same potential. If the joint has a greater resistance than the rail section, a balance can be obtained by moving the switch to the left, thus virtually shifting point h along the resistance until the voltage drops through the two resistance sections gh and hk become equal to the voltage drops through the corresponding rail sections ab and bc .

83. It is hardly possible to obtain such an exact balance that there will be no sound whatever in the telephone, but the point where the sound is a minimum can be quickly found. The interrupter is used to make a clicking sound in the telephone, as the fluctuations in the rail current would not in themselves be regular enough to give an easily detected sound.

In this type of instrument as actually constructed, the contacts of the multipoint switch *s*, Fig. 48, are numbered so as to read off the resistance of the joint in terms of a 3-foot length of rail. Thus, if balance is obtained with the switch on point 1 it indicates that the joint has a resistance equal to 3 feet of rail. If a balance is obtained on 1.5, the joint resistance is equal to 1.5×3 or 4.5 feet of rail; if a balance is obtained on 2, the joint resistance is equal to 6 feet of rail. Readings from 1 to 2 are considered as indicating good bonding; readings on points 3 or 4 indicate poor bonding; all readings above 4 indicate very poor bonding. For any given class of bonding, the point at which the switch should give a balance for a good joint is known, and bad joints can therefore be easily detected. Good bonding will never have a resistance greater than twice the same length of rail, and in the better class of work it will not exceed 1 to 1.5 times an equal length of rail; in fact, if proper care is taken, there is no reason why the joint resistance should not be less than that of a 3-foot rail length, particularly if solid rail joints are used.

84. Everett-Edgcumbe Bond Tester.—The connections of a bond tester with which exact balance can be obtained, and in which the telephone and interrupter are replaced by a portable galvanometer, are shown in Fig. 49. Its principle of operation is the same as that of the telephonic bond tester. The contacts *a*, *b*, and *c* consist of sharp-toothed steel blades, which bite into the rail, thus making good contact, and they are attached to a springy wooden bar fitted with a handle *d*. The two end contacts *a* and *c* are connected to the terminals *e*, *f* of a stretched wire. The middle contact *b* is joined through the switch *g* and galvanometer *h* to a movable contact *i*, which travels along the slide wire. This movable contact carries with it a pointer, which

moves over a dial graduated to read the resistance of the joint in terms of feet of solid rail. Exact balance can be obtained with this instrument, because the resistance of that part of the slide wire between *e* and *i* can be made to bear any ratio to the resistance of the part between *i* and *f*. The number of ratios obtainable is infinite, and is not limited, as in the telephonic bond tester, by the number of stops provided on the resistance. It would, however, be easy to replace the resistance and stops in the telephonic device by a slide wire. The galvanometer *h*, Fig. 49, is specially constructed for portability, and is carried, together with the slide wire, in a box attached to a shoulder strap.

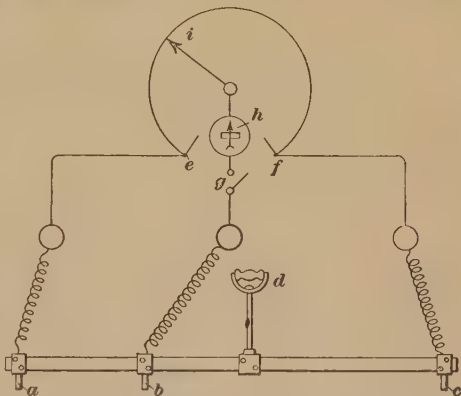


FIG. 49

ELECTROLYSIS

85. General Effects of Electrolysis.—The subject of **electrolysis**, which is here taken to mean the eating away of the rails, underground pipes, or other buried metallic conductors by stray currents from the tramway system, is closely connected with the feeding system, especially with the track-return part of it. When electrolysis was first noticed, a great outcry was raised against the systems with a rail return by gas and water companies, telephone companies, and other corporations owning underground pipes or lead-covered cables.

This led to an investigation of the subject, with the result that stringent regulations were framed by the Board of Trade, limiting the voltage drop in the rails, the effect of which has been to reduce the damage due to the leakage current to a negligible quantity.

86. **Elementary Principles.**—If the terminals of two iron plates *A* and *B*, Fig. 50, which are buried in damp earth, are

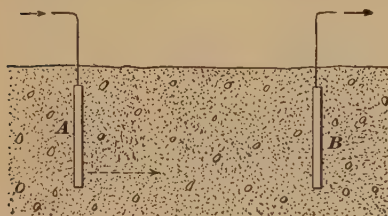


FIG. 50

connected to a direct-current generator, and a current made to flow from *A* to *B* through the earth, plate *A* will be eaten away or pitted, while plate *B* will not be damaged. This is practically the same electrochemical effect that takes place in

electroplating, where metal is taken from a plate, or anode, from which current enters the chemical solution or electrolyte, and deposited on the article to be plated, which is always placed where the current passes out of the solution. The point to notice is that wherever current flows *from* a metal conductor into an electrolyte or damp earth, the conductor is eaten away, provided that the difference of potential between the conductor and the adjacent earth is sufficient to effect the chemical decompositions; but where current flows *from* the earth *into* the conductor, the latter is not damaged. The rate at which the metal will be eaten away depends on the strength of the current.

TABLE XI

ELECTROLYTIC EFFECT OF CURRENT
ON VARIOUS METALS

Metal	Grammes Per Ampere-Hour	Pounds Per Ampere Per Year
Aluminium . . .	·327	6·31
Copper . . .	1·190	22·97
Iron . . .	1·044	20·15
Lead . . .	3·852	74·34
Tin . . .	2·218	42·71
Zinc . . .	1·216	23·47

87. Table XI shows the weight of metal that will, theoretically, be eaten away by 1 ampere flowing steadily for 1 year, for metals likely to be affected by stray underground

currents. This table is of interest chiefly because it shows the relative effect of a current on the different metals.

88. It does not follow that, in practice, whenever a current of 1 ampere flows for 1 year from a conductor into the ground, the amounts of metal indicated by Table XI will be eaten away. In fact, under some circumstances current may flow from a buried conductor to the ground without eating the metal at all. For example, the elements or compounds liberated by the current may be such that no corroding action takes place on the pipe, or the energy expended per unit area of the pipe surface may not be great enough to decompose the salts in the damp earth. It has also been found in many cases that electrolytic action may take place for a while and then cease, owing to the character of the earth round the conductor having become changed by the decomposition of the salts contained therein and rendered incapable of acting as an electrolyte for further electrolytic action.

89. It should be remembered that underground pipes and conductors may become corroded by the simple chemical action of the salts contained in the earth, and it by no means follows that whenever a conductor or pipe shows signs of pitting the corrosion is due to electrolysis; in fact, there is no sure way of telling simply from the appearance of the pipe to which source the corrosion is due.

In Table XI, it is interesting to note that lead is eaten away more rapidly than any of the other metals there given. Underground lead pipe and the lead sheaths of underground cables are, under like conditions, eaten away much more rapidly than iron pipe. The corrosion never takes place evenly, but in spots, so that the pipe or sheath becomes pitted, and is soon destroyed. However, the general practice now is to run underground cables in earthenware ducts or conduits, which form an insulating medium between the cable sheath and earth, thus preventing electrolysis to a large degree. Wrought-iron pipe is much more susceptible to electrolytic corrosion than cast-iron; with cast iron the impurities in the iron appear to form a kind of scale on the surface that protects the pipe. The harder grades of cast iron, such as chilled iron, seem to be very little affected by electrolysis under ordinary conditions.

90. Electrolysis Due to Tramway Currents.—A diagram showing how electrolysis may occur in connection with an overhead trolley system is given in Fig. 51. Current is supplied to the car *C* by means of the trolley wire *T*. The track *R* under ordinary conditions acts as the conductor for the return current, as indicated by the arrows. If, however, there happens to be a pipe *L*, in the neighbourhood of the track, that offers a ready path for the current, part of the current will leave the rails, as at *I*, enter the pipe, and flow out again at *O* to return to the power station *P*. At *O*, where the current leaves the pipe, electrolytic action will be set up, if the conditions are favourable, and in the course of time holes will be eaten in the pipe. At *I* the current leaves the rails; hence, they will be eaten away to some extent. If the trolley wire were connected to the negative



FIG. 51

pole of the generator instead of the positive, the current would flow out through the track, and whatever corrosion occurred on the pipes would take place at points removed from the station and would be scattered over a wide area. On the other hand, with the positive pole connected to the trolley, whatever action takes place on the pipes is confined to districts near the power house. These areas are comparatively small, and measures can be taken to protect them. This is the chief reason why the positive pole of the generator should be connected to the trolley side of the line.

91. With an arrangement of track and pipes such as shown in Fig. 52, the current may leave the rail *r*, enter the pipe *w*, and flow through *w* until a better path presents itself in the shape of the lead-sheathed cable *c*. It then flows along *c* until the track

presents a better path, when it returns to the rail again, as indicated by the arrows. Electrolytic action may occur where the current leaves the rail, the iron pipe, and the lead sheath of the cable.

It will be seen, by referring to Fig. 51, that if the track return is in good condition, there will be little inducement for the current

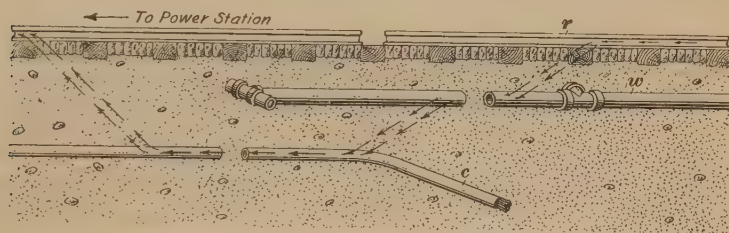


FIG. 52

to leave the track and pass through the intervening earth to come back on the pipes. One of the most effective precautions against electrolysis is thorough rail bonding. Systems in which both go and return conductors are insulated are, of course, free from the liability to cause electrolysis.

92. Prevention of Electrolysis.—The rules laid down by the Board of Trade for the prevention of electrolysis, and the periodic tests which they require to be made to ensure the observance of these rules, have been enumerated elsewhere ; the arrangement of the switchgear necessary for the tests has also been described. The result of these regulations and tests is that the drop of pressure in the rails is limited to 7 volts, that the difference of potential between any pipe or cable sheath and the rail is limited to about $4\frac{1}{2}$ volts if the rail is positive to the pipe, and to about $1\frac{1}{2}$ volts if the pipe is positive to the rail, and that the current returning to the power station through the earth is limited to 2 amperes per mile of single track, or 5 per cent. of the total current output. With regulations such as these, it is found that electrolysis is practically negligible.

93. Negative Feeders.—In order that the drop of pressure in the rails shall not exceed 7 volts, it is necessary to connect them

at intervals to insulated cables, called **negative feeders**, or **return feeders**, which carry part of the current from the rails back to the power station. These cables are of the ordinary type, and are run underground in ducts or conduit; they are attached to the rails in the same manner as bonds. Fig. 53 shows a method of

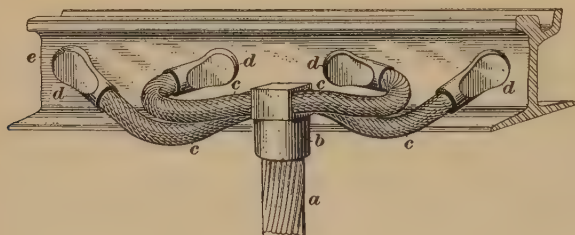


FIG. 53

connecting a negative feeder to the rail. The feeder cable *a* is attached to the copper terminal *b*, into which are fused the flexible conductors *c*. These conductors are cast into the bond terminals *d*, which are attached to the rail web *e* by any of the methods used for making bond connections.

94. Negative Boosters.—In order to reduce the size of the negative feeders required to keep the rail drop within the specified limit, the power-station ends of the feeders are connected to the negative bus-bars through **negative boosters**. These are small direct-current series generators, which are designed to carry the

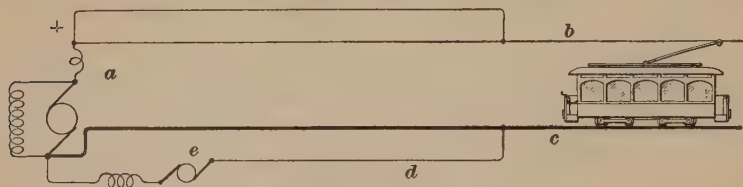


FIG. 54

whole current in the feeder, and to generate a voltage equal to that lost in the feeder, so that it is possible to use a feeder in which there is a fairly large drop in pressure. They are often driven by shunt motors supplied from the main bus-bars. The way in which the feeders and boosters are connected is indicated

in Fig. 54, where a is the main compound generator, the positive pole of which is connected to the trolley wire b . The rails c are connected through the return feeder d to the negative terminal of the series-wound negative booster e , the positive terminal of which is connected to the negative terminal of the generator a .

95. The action of the negative boosters will be made more clear by the consideration of a simple numerical example. Suppose that Fig. 55 represents a tramway system supplying current to a number of cars equally distributed over the whole length of the line. This is equivalent to a load equal to the sum of all the currents taken by the separate cars, this load being situated in the mean position, that is, at a , half-way along

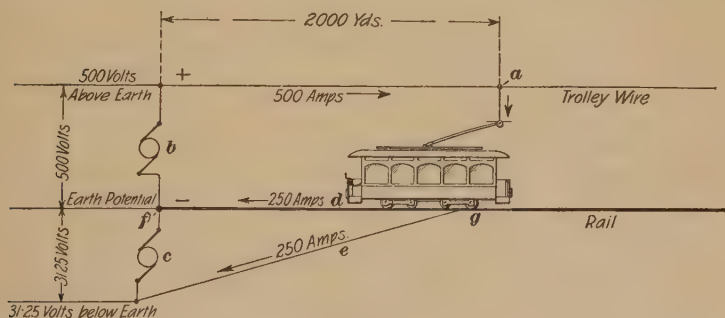


FIG. 55

the line. The current is assumed to be 500 amperes, and a is 2,000 yards from the generating station, which contains the main generator b and the negative booster c . The track d is supposed to consist of British Standard No. 2 rails, which, from Table II, have a weight of 95 pounds per yard, and from rule I, Art. 9, a sectional area of 9.5 square inches.

96. From rule I, Art. 59, the resistance per yard of rail is $\frac{.0025}{95} = .0000263$ ohm. The resistance of 2,000 yards is therefore $2,000 \times .0000263 = .0526$ ohm. The resistance of 2,000 yards of track, consisting of two rails in parallel, is therefore $\frac{.0526}{2} = .0263$ ohm. If there is no negative feeder or

booster, the drop in volts in rails = current $\times$ resistance of rails = $500 \times .0263 = 13.15$ volts. As this drop exceeds the 7 volts allowed by the Board of Trade, steps must be taken to reduce it to half its present value. There are two methods available for doing this, the first being to use a negative feeder alone, and the second to use a negative feeder in connection with a negative booster. As the drop, and consequently the current in the rails, must be reduced to one-half, the resistance of the negative feeder e , Fig. 55, if used without a booster, must be equal to the resistance of the track between f and g in order that feeder and track may share the current equally. The total sectional area of the two track rails is $2 \times 9.5 = 19$ square inches. The specific resistance of steel has been taken as 10 times that of copper, so that the sectional area of copper in the feeder, assuming that the feeder is of the same length as the track between f and g , is $\frac{19}{10} = 1.9$ square inches. The cost of a

feeder with such a large area of copper would be quite prohibitive, and a smaller cable, in conjunction with a negative booster, would be used.

97. The capacity of the negative booster required in the case which has just been outlined would be found in the following way: The current to be carried by the cable is 250 amperes. Assuming that the sectional area of the cable to be used is .4 square inch, which would carry the current safely without undue rise of temperature, the resistance of 2,000 yards of this cable would be equal to that of 2,000 yards of rail of an area of $.4 \times 10 = 4$ square inches. The weight of this rail would be 40 pounds per yard, and its resistance per yard would be $\frac{.0025}{40} = .0000625$ ohm. The resistance of 2,000 yards of the rail, and therefore of 2,000 yards of cable .4 square inch in sectional area, would be $.0000625 \times 2,000 = .125$ ohm. The drop in pressure along this cable would thus be $250 \times .125 = 31.25$ volts. The booster would have to compensate for this drop, with 250 amperes passing through it, and its capacity would therefore be $30 \times 250 = 7,500$ watts = 7.5 kilowatts.

The duty of the booster is thus to provide the E.M.F. necessary to make the current return along a cable which is of higher resistance than the track. The size of the return cable was assumed in the above example, but would in practice be fixed by the carrying capacity of the cable, and by Kelvin's law, which states that the annual cost of the watts lost in the cable should equal the annual amount of interest on the cost of the cable plus an allowance for depreciation of the cable.

TRAMWAY OVERHEAD WORK

MECHANICAL CONSIDERATIONS

SUSPENSION OF TROLLEY WIRES

RELATIVE POSITIONS OF WIRES AND TRACK

1. **Centre- and Side-Running Systems.**—In the system of tramways and railways known as the **overhead system**, the current is supplied to the car from a conductor suspended within reach of a collector carried by the car. If the conductor is suspended immediately above the centre of the track, the system is said to be **centre-running**; if the conductor is suspended at some distance from the centre of the track, the system is said to be **side-running**. The overhead conductor is usually known as the **trolley wire**. The centre-running system is the mechanically correct one, and side running is only adopted when it involves a cheaper and less unsightly construction, or when such mechanical difficulties are encountered as the presence of telegraph wires or road obstructions. The side-running system is also used at low bridges, where it is necessary to place the wires at one side, so as to give sufficient clearance for passengers on tops of cars. In side-running systems the distance of the trolley wire from the centre of the track should not exceed 8 feet, or there may be considerable trouble caused through collectors leaving the wires.

TYPES OF OVERHEAD CONSTRUCTION

2. **Span-Wire Construction.**—One of the simplest and most satisfactory methods of suspending the trolley wire is to hang

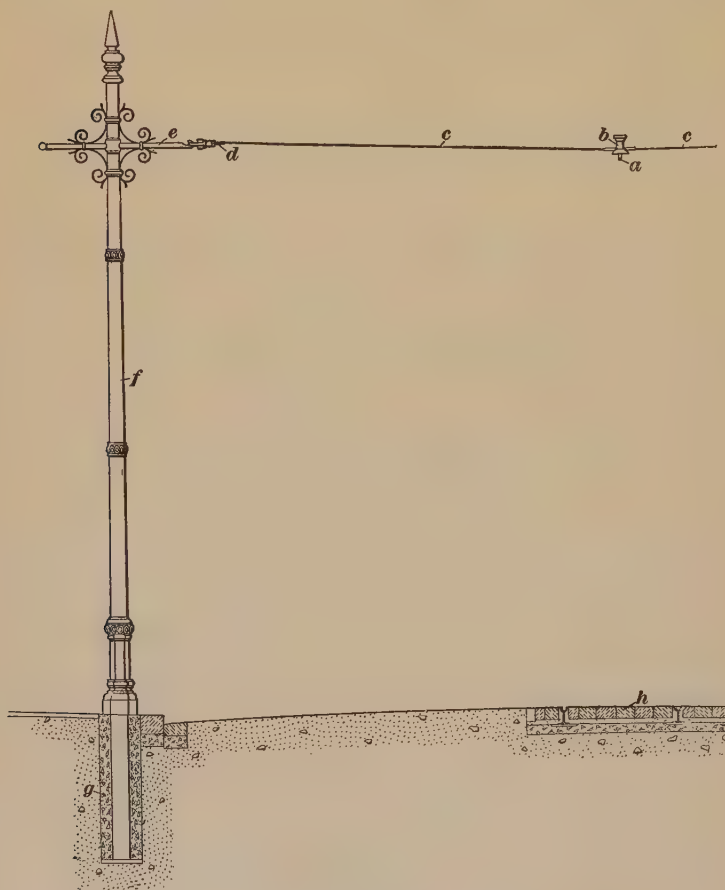


FIG. 1

it by means of insulators from a steel span wire stretched between poles on opposite sides of the track. This method is known as the **span-wire construction**, and is very extensively used both in Great Britain and abroad. This type of construction is shown in Fig. 1, which illustrates the arrangement for

centre-running on a double track. The construction is only shown for one half of the street, the other half being exactly similar. The trolley wires *a* are supported by the insulated hangers *b*, which are attached to the steel span wire *c*. Where trolley wires are suspended from span wires, the Board of Trade requires that there shall be double insulation between the trolley wire and earth. On this account the span wire *c* is terminated at each end in the insulators *d*, which are so constructed that the tension on the span wire can be adjusted. The insulators *d* are attached to brackets *e* fixed to the posts *f*, which are embedded in concrete *g*. Each trolley wire is vertically above the centre of its track *h*. The Board of Trade regulations provide that the height of the trolley wire above the surface of the roadway must not be less than 20 feet, except where the line passes under low bridges.

3. Advantages of Span-Wire Construction.—The span-wire construction has many advantages, the chief of which are that it does not obstruct the centre of the roadway, and it gives a very flexible support to the trolley wire. Also, where a single track is laid, with the prospect of making it a double track if the traffic warrants doing so, the span-wire construction leaves very little additional work to be done when the time comes for doubling the track. In such a case, it is sometimes the practice to erect two trolley wires side by side, about 8 or 10 inches apart. As long as the road is single track, the cars use one wire when going one way and the other wire when returning; this saves overhead special work at turnouts and saves copper in the feeder cables. When the time comes for doubling the track, it is only necessary to slide one wire into place over the new track.

In Fig. 2, *ab* is one trolley wire and *cd* is the other; *T* is a turnout where cars can pass each other. The dotted line *ef* shows the position of the wire *ab* after it has been moved over to the second track. In Fig. 1 the poles are placed in the kerb line, but in some cases they are placed at the back of the path

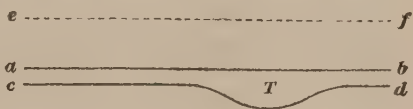


FIG. 2

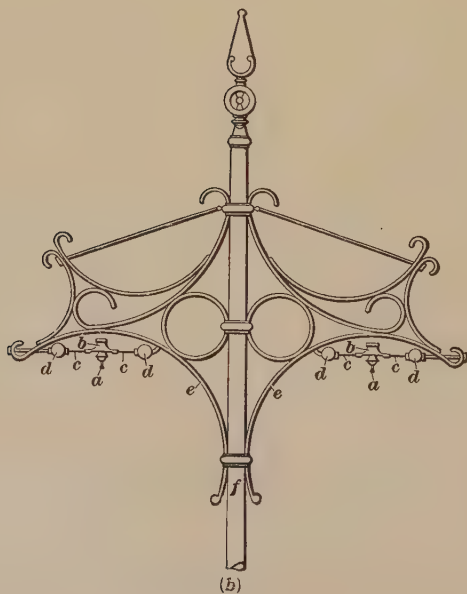
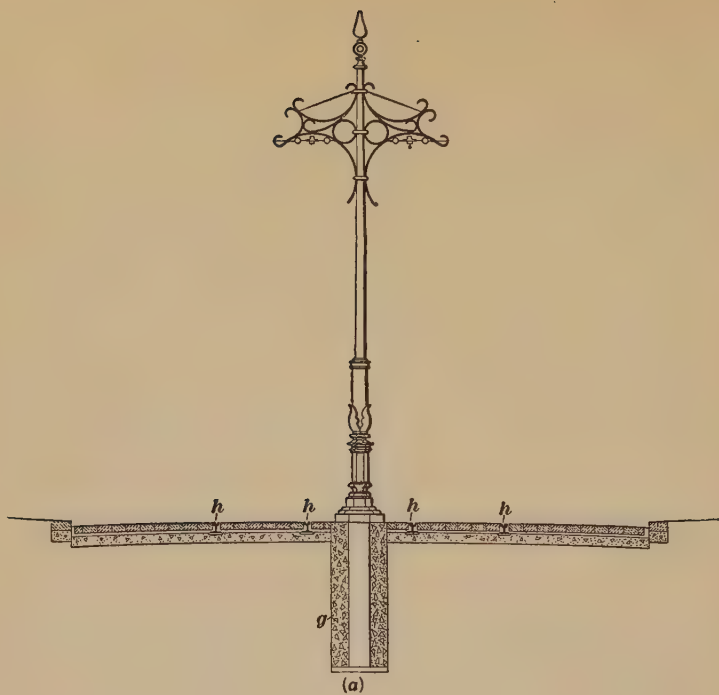


FIG. 3

to avoid obstructions, or to suit the wishes of the district surveyor.

4. **Centre-Pole Construction.**—In very wide roads, where the presence of poles in the centre of the road is not objectionable, the centre-pole construction is often adopted. This method of



FIG. 4

suspending the trolley wires for side-running on a double track is shown in Fig. 3 (a); in view (b) is shown the top of the pole drawn to a larger scale. The trolley wires *a*, view (b), are supported by the insulated hangers *b*, which are carried by short lengths of steel wire *c* fixed to strain insulators *d*. These strain insulators are attached to the brackets *e*, which are clamped to

the pole *f*. The poles are set in concrete *g*, as before. The trolley wires are suspended almost directly above the inside lines of rails of the track *h*. This type of construction is cheaper than the span wire, as it enables the two trolley wires necessary for a double track to be carried by a single line of poles.

5. **Side-Bracket Construction.**—Where the trolley wires can be supported, not more than 8 feet from the centre of the track, by an arm not exceeding 16 feet in length, the **side-bracket construction** is often used. In some cases arms over 20 feet long have been used, but such arms are mechanically weak, and should only be adopted where the span-wire system is not permissible. The side-bracket construction is shown in Fig. 4, where the arrangement of insulators, etc., is the same as for the other types of construction. Part of the weight on the bracket arm *a* is taken by the tie-rod *b*, and the bracket is further strengthened by the ornamental scrollwork *c*. In both the centre-pole and side-bracket types of construction, the insulators supporting the trolley wire are usually carried by short lengths of span wire. This enables the necessary double insulation to be provided between the trolley wire and earth, and also provides an elastic support for the trolley wire, to absorb the blow given by the collector when passing the point of support of the trolley wire. The life of the trolley wire and support is thus much increased.

POLES AND ROSETTES

6. **Types of Poles.**—The poles used for tramway work in Great Britain are of mild steel, although wooden poles are used in America and on the Continent. The steel poles are commonly *tubular poles*, though *lattice poles* are occasionally used; the latter, however, find a larger application in railway work.

7. **Tubular Poles.**—Tubular poles are generally made in three sections, each of which is a solid-drawn tube, or a tube made by rolling a steel plate into tubular form and lap welding the edges. When the poles are made of lap-welded tube, the welds in the three sections are placed at 120° to one another. The sections of the poles are welded together under pressure.

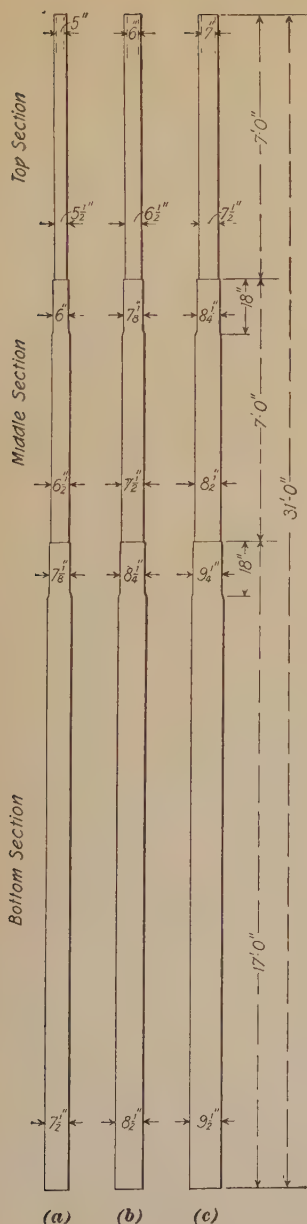


FIG. 5

Tubular poles are also made from one length of steel plate, turned over and butt-welded along its whole length. When this method of construction is adopted, the poles are tapered, and are called taper poles.

8. Sectional poles are made in three standard sizes, *light*, *medium*, and *heavy*. They are 31 feet long and the joints between the sections are 18 inches long. Their dimensions are shown in Fig. 5, where (a) is a light pole, (b) a medium pole, and (c) a heavy pole. Each pole is usually fitted with ornamental cast-iron collars at the joints, a cast-iron base, and a cast-iron top, known as a *finial*. The connection of the span wires to the poles is made either to a light steel strap clamped round the pole or to a short bracket clamped to the pole and fitted with ornamental scrollwork. The light poles may be used on straight runs for bracket work and for span work where the span is not too great. Medium poles should be used for brackets having arms from 7 to 16 feet long, for wide spans, and on curves. Heavy poles should be used for terminal and anchor poles, and where there are complicated junctions.

9. Tests for Standard Poles. Standard tramway poles are usually required to conform to the following tests, a certain percentage of each batch being selected for testing purposes:

(a) The pole shall be dropped vertically, butt downwards, three

TABLE I

STANDARD TESTS FOR STEEL
TRAMWAY POLES

Class of Pole	Load for Temporary Deflection not Exceeding 6 Inches Pounds	Load for Permanent Set not Exceeding $\frac{1}{2}$ Inch Pounds
Light .	750	1,000
Medium	1,250	1,750
Heavy .	2,000	2,500

times in succession, from a height of 6 feet, on to a hard wooden block 6 inches thick laid on a concrete foundation, and shall not show any signs of telescoping or loosening of joints. (b) The pole shall in each case be rigidly supported for 6 feet from the butt, and loaded,

as a cantilever, 18 inches from the top, the load being applied at right angles to the axis of the pole, which shall be fixed horizontally. On the application of the loads given in Table I, the temporary deflection and permanent set, measured at the point of application of the load, shall not exceed 6 inches and $\frac{1}{2}$ inch, respectively. The standard taper poles are not subjected to the first test, because they are made in one piece, but both sectional and taper poles must pass the second test.

10. Lattice Poles.—Lattice poles are very largely used on the Continent for work in suburban and country districts, and have been recently used for tramway work in Great Britain. The method of constructing them is shown in Fig. 6. The type shown in view (a) consists of two steel channels *a*, braced together by steel strips *b*; that shown in view (b) consists of four steel angles *c* arranged in a square, and tied together on all four sides by the steel strips *d*. For tramway work, the poles formed in either of these ways are tapered off along their length, being large at the base and small at the top. For railway work, the sides are usually parallel throughout their length.

11. Erection of Poles.—Tramway poles are usually set 6 feet in the ground and surrounded by concrete. The thickness of concrete required depends on the nature of the soil, the looser the soil, the thicker being the layer of concrete necessary; the usual thickness for ordinary construction is about 9 inches. A slab of concrete or stone should be placed at the bottom of the hole for the pole to stand on; this will tend to prevent sinking. When excavating holes for the poles, the surrounding

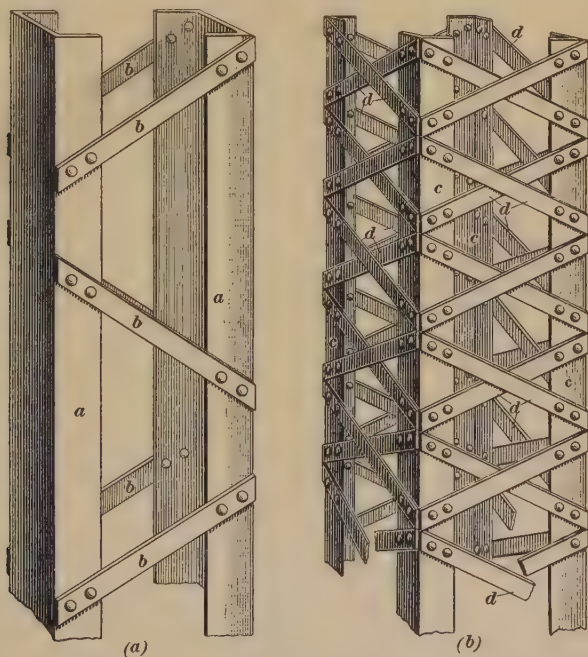


FIG. 6

soil should not be disturbed more than is absolutely necessary, and only concrete should be used for filling the hole. When erected, the poles are given such a rake that when the trolley wire is strung in position the poles will be as nearly vertical as possible. The amount of this rake depends on the strength of the pole, the weight of the overhead fittings, the nature of the soil, the width of street in the case of span wires, and the length of the bracket for side-bracket construction. It varies from

about 3 inches for light straight-line work to 12 inches for heavy curves and terminal posts. Centre poles for straight-line work should be erected vertically, for the bending effect due to the wire on one side counteracts that on the other. The maximum distance apart between the poles in the direction of the track is limited by the Board of Trade to 120 feet. After erection, the poles should be allowed to set for from 5 to 7 days before the trolley wire is erected.

12. Rosettes.—In cases where there are substantial buildings along the tramway route, and the necessary permission can be

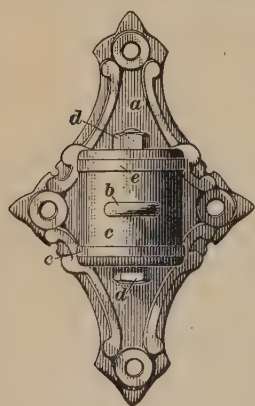


FIG. 7

obtained, the poles may be dispensed with, and attachments made to the buildings by means of **rosettes**, the span-wire construction being used. A common type of rosette is shown in Fig. 7. It consists of an ornamental casting *a* that is attached to the building by means of four special bolts. The insulator or span wire is then attached to the eye-bolt *b*, which is screwed into a circular casting *c*. This circular casting has a hole through its centre which is bushed with rubber, and it is attached to the lugs on the main casting *a* by means of the bolt *d*, which passes through the

bush. This rubber bush prevents the vibration of the trolley wire being transmitted to the buildings; large rubber washers *e* further help to deaden the vibration. The use of rosettes cheapens the cost of the overhead construction to a very great extent, but they can seldom be used for any considerable distance.

SPAN AND GUARD WIRES

13. Span Wires.—Span wires for supporting the trolley wires nearly always consist of stranded galvanized-steel wires. The number of strands used in British practice is in most cases uneven. For ordinary straight construction, a span wire

consisting of 7 strands of No. 12 S.W.G. is often used. The sizes and breaking loads of various sizes of span wire are given in Table II.

TABLE II
STRANDED GALVANIZED-STEEL WIRES

Gauge of Each Strand S.W.G.	Diameter of Each Strand Inch	Number of Strands	Approximate Diameter of Stranded Wire Inch	Approximate Breaking Load Pounds	Approximate Weight Per 100 Feet Pounds
8	·160	7	$\frac{1}{2}$	8,320	52·00
9	·144	7	$\frac{1}{8}$	6,050	42·50
10	·128	7	$\frac{3}{8}$	4,550	28·75
12	·104	7	$\frac{5}{16}$	3,950	18·62
14	·080	7	$\frac{1}{4}$	2,400	12·12
17	·056	7	$\frac{3}{16}$	1,600	8·75

14. **Guard Wires.**—Where telegraph or telephone wires, unprotected by an insulated covering, are liable to fall or be blown on to the trolley wires, the Board of Trade enacts that **guard wires** shall be provided over trolley wires. These guard wires must be efficiently earthed. The smallest size permitted is 7 strands of No. 16 S.W.G., or a single strand of No. 8 S.W.G. The earth connection should be made by connecting the guard wire through the support to the rails by means of a copper bond. The guard wires are generally carried by the same poles as the trolley wires. The various arrangements of guard wires are shown in Fig. 8 (*a*) to (*e*), in which the trolley wires are lettered *a* and the guard wires *b*.

15. Where telephone wires weighing less than 100 pounds per mile cross the trolley line, the Board of Trade regulations are as follows :

(*a*) Where there is one trolley wire, two guard wires should be erected, as shown in Fig. 8 (*a*). (*b*) Where there are two trolley wires at a distance not exceeding 12 feet apart, two guard wires should be erected, as shown in view (*b*). (*c*) In special cases, at junctions or curves, where parallel guard wiring would be complicated, two guard wires only will generally suffice if so erected that a falling wire must fall on them before it can fall on the trolley wire.

When the wires which cross the overhead work weigh over 100 pounds per mile, the regulations are as follows:

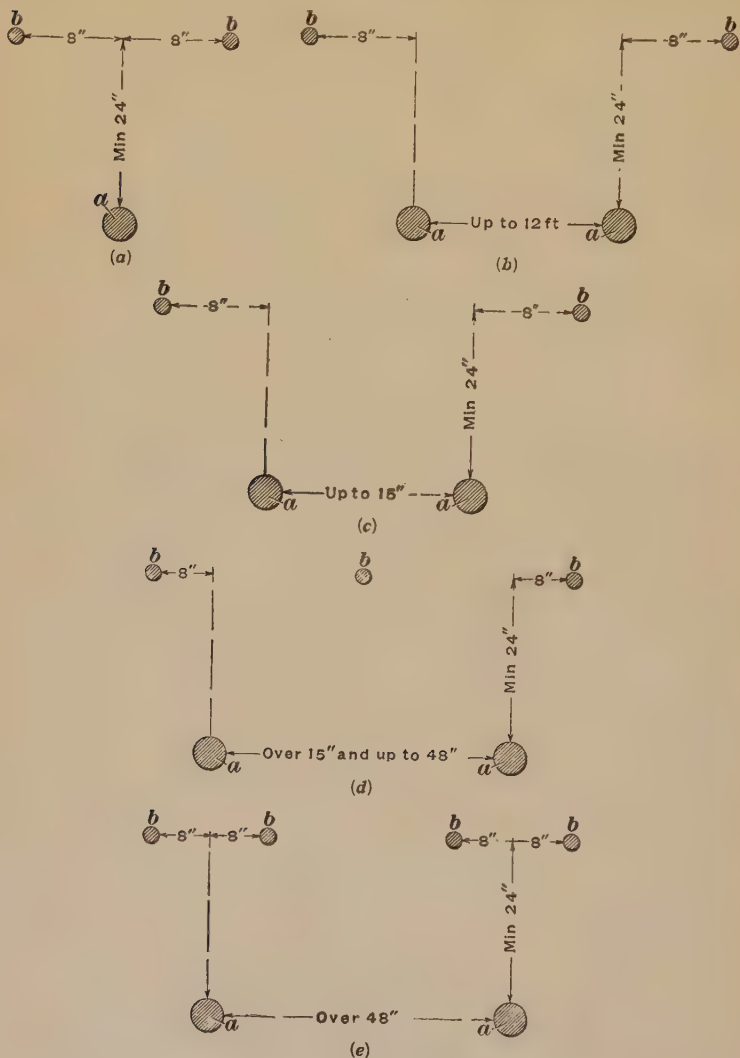


FIG. 8

(a) Where there is only one trolley wire, two guard wires should be erected, as shown in view (a). (e) Where there are two trolley wires not

more than 15 inches apart, two guard wires should be erected, as shown in view (c). (f) Where there are two trolley wires and the distance between them exceeds 15 inches, but does not exceed 48 inches, three guard wires should be erected, as shown in view (d). (g) Where the distance between the two trolley wires exceeds 48 inches, each trolley wire should be separately guarded, as shown in view (e).

16. Where telegraph or telephone wires run parallel to a trolley wire, or are liable to fall on, or to be blown on to, a trolley wire, a guard wire should be so erected that a falling wire must fall on the guard wire before it can fall on the trolley wire. If the trolley wire is enclosed within a triangle formed by the vertical plane of a telegraph wire and an imaginary line drawn at an angle of 45° from the uppermost telegraph wire on the side nearest to the trolley wire, a guard wire should be erected on span wires or on the brackets. This indicates the minimum requirements. In very exposed situations, or for heavy routes of wires, more than one guard wire may be needed. When guard wires are attached to other supports than the poles carrying the trolley wires, they should be connected with the rails at one point at least. When it is possible that a telegraph wire may fall on an arm or a stay, or a span wire, and so slide down on to a trolley wire, guard hooks should be provided.

17. If the guard wires are so arranged that the fallen wire cannot make contact with a trolley wire without also touching a guard wire, the trolley wire will be earthed, and the circuit-breaker at the power station will open. Small fuses or heat coils are placed in the circuits of all telegraph and telephone instruments, so that, in the event of a connection with any tramway or electric-light wires, the fuses will blow and protect the instruments. Many engineers are opposed to the use of guard wires, but there is no doubt that the best procedure is to avoid overhead crossings altogether, and to run all telegraph and telephone cables underground, either altogether, or at least at crossing points. The resistance to earth of all guard wires should be periodically tested, in order to see that the earth connections are in good condition. For the guard wires to be really effective, their connections to the track rails should be solidly made, and be of negligible resistance.

TROLLEY WIRE AND FITTINGS

TROLLEY WIRE

18. Copper Trolley Wire.—The trolley wire used for all ordinary work is of hard-drawn high-conductivity copper. It is seldom less than No. 0 S.W.G., while No. 00 is the size most frequently used. Some of the roads recently built use No. 000 or No. 0000, as it gives a stronger construction in addition to reducing the voltage drop. If the feeding system is laid out

TABLE III
HARD-DRAWN COPPER TROLLEY WIRE

Gauge	Diameter Inch	Sectional Area Square Inch	Weight Per 1,000 Yds. Pounds	Weight Per Mile Pounds	Breaking Stress Pounds
0000000 S.W.G.	·500	·1964	2,276	4,005	9,150
000000 S.W.G.	·464	·1691	1,955	3,441	8,330
0000 B. & S.	·460	·1661	1,921	3,381	8,370
00000 S.W.G.	·432	·1466	1,695	2,983	7,390
000 B. & S.	·410	·1320	1,527	2,687	6,790
0000 S.W.G.	·400	·1257	1,453	2,557	6,450
000 S.W.G.	·372	·1087	1,256	2,212	5,600
00 B. & S.	·365	·1046	1,209	2,129	5,390
00 S.W.G.	·348	·0951	1,100	1,935	4,900
0 B. & S.	·325	·0829	958	1,692	4,270
0 S.W.G.	·324	·0824	953	1,678	4,250

properly, larger wires are quite unnecessary. Hard-drawn copper is used because its tensile strength is greater and its wearing qualities better than soft copper. Its resistance is slightly higher, but this is of little consequence because the trolley wire is not usually depended on to carry the current for any great distance. Table III gives particulars of size, weight, and tensile strength

for some of the standard sizes of hard-drawn copper. The variation in diameter should in no case exceed $\cdot0005$ inch.

19. Special Trolley Wire.—For curves and other places where the wear and strain on the trolley wire are greater than usual, special composition trolley wire is sometimes used. One of the best compositions is **silicium bronze**, the breaking stress of which is

TABLE IV
SILICIUM-BRONZE TROLLEY WIRE

Gauge	Diameter Inch	Sectional Area Square Inch	Weight Per 1,000 Yds. Pounds	Weight Per Mile Pounds	Breaking Stress Pounds
0000000 S.W.G.	$\cdot500$	$\cdot1964$	2,276	4,005	13,940
000000 S.W.G..	$\cdot464$	$\cdot1691$	1,955	3,441	12,130
00000 S.W.G. .	$\cdot432$	$\cdot1466$	1,695	2,983	10,670
000 B. & S. . .	$\cdot410$	$\cdot1320$	1,527	2,687	9,740
0000 S.W.G. . .	$\cdot400$	$\cdot1257$	1,452	2,557	9,390
000 S.W.G. . . .	$\cdot372$	$\cdot1087$	1,257	2,212	8,150
00 B. & S. . . .	$\cdot365$	$\cdot1046$	1,209	2,129	7,960
00 S.W.G.	$\cdot348$	$\cdot0951$	1,099	1,935	7,240
o S.W.G.	$\cdot324$	$\cdot0824$	953	1,678	6,370

about one-third greater than that of hard-drawn copper. Its wearing properties are much greater, and its conductivity is about 70 per cent. The weights, sizes, and breaking stresses for some of the gauges in which it is made are given in Table IV.

EARS

20. Soldered Ears.—In order to support the trolley wire in position, gunmetal fittings, called **ears**, are attached to it at the span wires or bracket arms. A common form of ear is shown in Fig. 9, (a) being a plan, and (b) a side view; views (c) and (d) show sections on the lines *AB* and *CD*, respectively. The groove *a* in the ear is placed over the trolley wire, and the sides of the

groove are hammered in. Flux is then applied and the trolley wire is firmly soldered to the ear, after which all superfluous solder is removed and the ear and trolley wire made perfectly

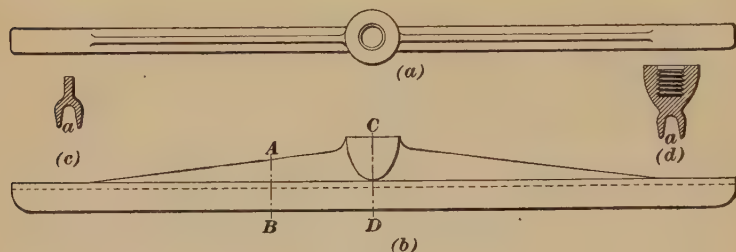


FIG. 9

smooth, as shown in Fig. 10, where *a* is the ear and *b* the trolley wire. In Great Britain, current is usually collected from the trolley wire by a grooved wheel, called a **trolley wheel**. On this account, the ear should not increase the diameter of the trolley wire very much, as hammering and sparking will result, and the life of the trolley wire will be determined by its life at the ears. Ears of this type should be carefully tapered off at the ends, so that the collecting wheel may pass under them without a jolt



FIG. 10

21. Mechanical Ears.—To get over the trouble caused by the jolting of the trolley wheel as it passes ears, trolley wires with grooved and figure-8 sections have been tried, in conjunction with mechanical ears screwed on to the wire, and so designed that the trolley wheel does not strike them in passing. The way in which the figure-8 section is held is shown in Fig. 11 (*a*), *a* being the ear between the jaws of which the trolley wire *b* is clamped by means of screws. Fig. 11 (*b*) shows the arrangement for a grooved-section trolley wire, the jaws *a* of the ear fitting into the grooves *b* in the trolley wire.

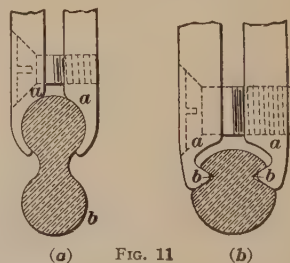


FIG. 11

22. A common type of mechanical ear for use with grooved wire is shown in Fig. 12, where *a* is the socket into which the supporting bolt is screwed, *b* the movable clamping jaw, *c* the clamping screws, and *d* the grooved wire. In erecting curve ears, care must be taken to keep the main casting on the inside of the curve, for if the clamps are placed on the inside the whole strain of the curve will come on the screw heads, which are liable to be sheared off. The special sections of trolley wire used with mechanical ears are not, however, very satisfactory. The figure-8 wire, when used in long spans, has a tendency to lie over on one side and throw the trolley wheel off the wire. Where a grooved wire is used for side-running, the wire wears away very quickly, the extreme edge of the section being gradually rolled into the groove, which soon disappears. For these reasons circular wires with soldered ears are by far the best, and are much more generally used than

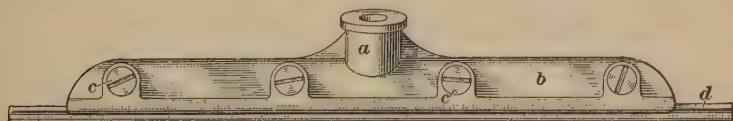


FIG. 12

special sections with mechanical ears. Ears for use on straight lines are commonly made 15 inches in length, but experience shows that a length of 24 inches gives much better results, and for curves, a length of 36 inches is more suitable.

23. **Special Ears.**—Some special types of ears, intended for soldering to the trolley wire, are shown in Fig. 13. The ear shown in (*a*) is known as a **strain**, or **anchor**, ear, and is so called because it is provided with eyes *a* to which anchor wires can be attached. In (*b*) is shown a **half-anchor** ear, which is only provided with one eye *a*. These types of anchor ears are soldered to the trolley wire at the points where breakages are most likely to occur, and the eyes are attached by means of short lengths of span wire to insulators fixed to the fittings. When the trolley wire breaks, it remains suspended from the anchor, and no long delay is caused to the cars, though the trolley must be lowered and the cars pushed past the faulty point. Fig. 13 (*c*) shows

a feeder ear, which is provided with a special connection *b* to which the feeder is attached. In Fig. 13 (*d*) is shown a splicing

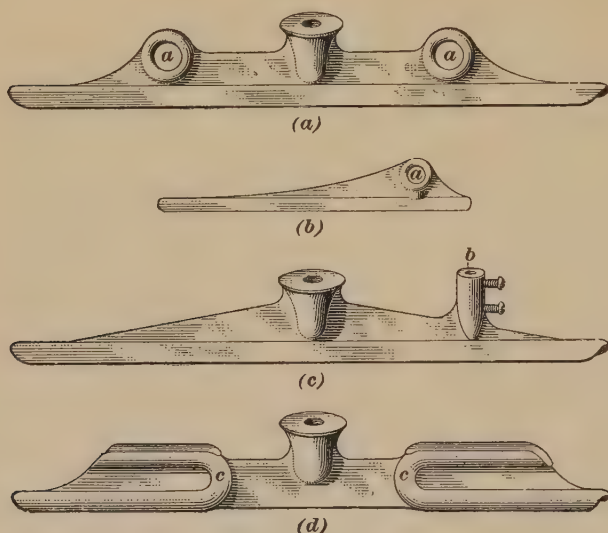


FIG. 13

ear, which is used where it is necessary to make a joint in the trolley wire at a hanger. The ends of the wire are passed up through the ear and bent over into the grooves *c*.

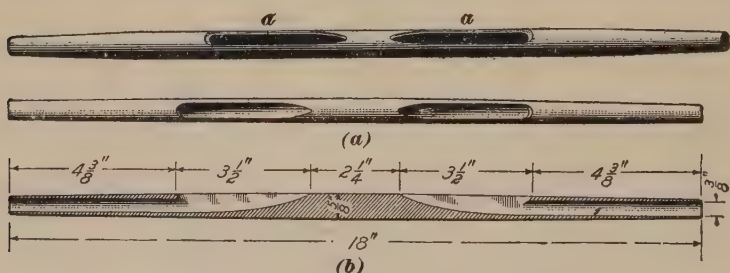


FIG. 14

24. When it is necessary to make a joint in the wire between hangers, a tinned tapering gunmetal sleeve, known as a **splicing sleeve**, is used. This device is shown in Fig. 14 (*a*) and (*b*); the ends of the trolley wires go in at each end of the sleeve and

are bent up through the openings *a, a*. The remaining space is then poured full of melted solder and the ends of the wire trimmed off. This connector will give excellent service if care is taken to see that it is made of heavy enough material and is a good fit for the wire. In view (*b*) are shown the dimensions for a satisfactory connector for No. 00 B. & S. wire. Splicing ears and splicing sleeves are very rarely used, owing to the fact that trolley wire is supplied in $\frac{1}{2}$ -mile lengths, and at the end of each $\frac{1}{2}$ mile a special fitting, called a *section insulator*, must be used.

INSULATING FITTINGS

25. Types of Insulating Fittings.—The insulating fittings used in overhead construction may be divided into three broad classes, according to the purposes for which they are used: (*a*) The fittings used to insulate the trolley wire from its supporting span wire or bracket, the chief of which are *straight-line hangers*, *double pull-offs*, and *single pull-offs*. (*b*) The fittings used to insulate the span wire from the poles or supports, known as *Brooklyn insulators*, *globe or strain insulators*, *insulated turnbuckles*, and *reel insulators*. (*c*) The fittings used to insulate two sections of trolley wire from each other, called *section insulators*.

26. Straight-Line Hangers.—The hangers for suspending the trolley wire in straight-line construction are made in a variety of designs, but in general they consist of a casting, or body, which is held by the span wire or bracket, and a bolt, cased in insulating material, from which the ear holding the trolley wire is suspended.

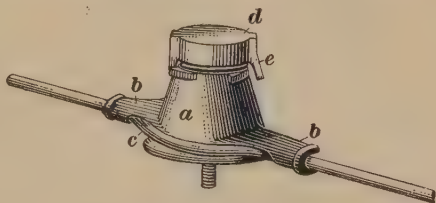


FIG. 15

A common form is shown in Fig. 15, where *a* is the main casting, which is provided with two grooved arms *b*. The span wire passes through the grooved arms *b* and presses into the groove on the main casting, as shown at *c*, thus holding the hanger in position. By using a special tool, hangers can be easily sprung into position on the span wire after it is

erected. The top of the hanger is covered by a screw-cap *d*, which is prevented from unscrewing by bending down the lugs *e* so that they engage with small projections from the casting *a*.

27. The construction of the straight-line hanger is shown in Fig. 16, (*a*) being a plan, (*b*) an elevation, and (*c*) a section on the line *A B*, view (*b*). The main body of the casting is shown at *a* and the grooved arms at *b*; *c* is the bolt round which is moulded the insulation *d*. The lower end *e* of the bolt is threaded so that it can be screwed into the ear to which the trolley wire is attached. Just above the screw thread the bolt is provided

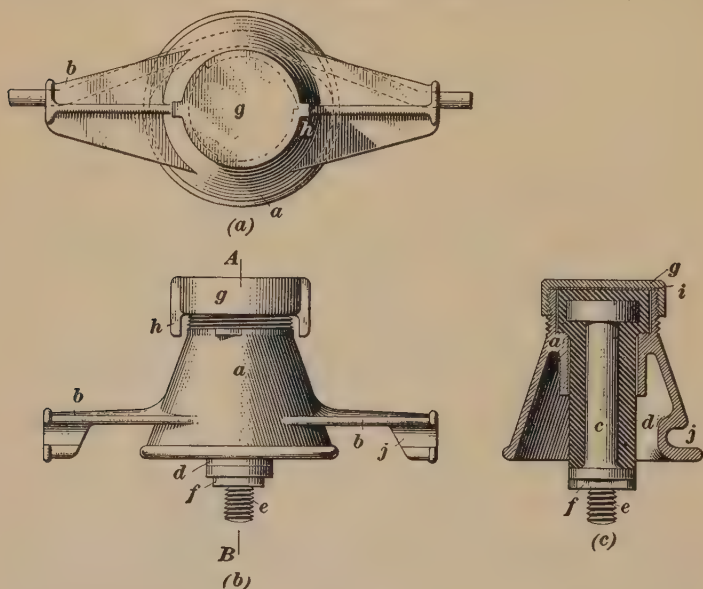


FIG. 16

with flat sides *f* to permit of its being gripped by a wrench and screwed into the ear. The whole of the insulated bolt is free to turn in the main body *a* of the casting; it is kept in place by the screw-cap *g*, the lugs which keep the cap from unscrewing being shown at *h*. The cap is prevented from damaging the insulation of the bolt, owing to being screwed on too tightly, by the leather washer *i*. The span wire rests in a groove *j* in the main casting. The advantages of this type of hanger are

that the insulation is completely protected from damage due to blows from the trolley arms of cars, that the insulating bolt can easily be replaced by removing cap *g* and unscrewing the bolt from the ear, and that even if the insulation of the bolt is entirely destroyed the trolley wire cannot fall, because the head of the bolt is too large to pass through the hole in the main casting.

28. The main castings of straight-line hangers are made both in galvanized malleable iron and in gunmetal. The iron hangers are the cheaper, but the gunmetal hangers are the more durable, as they resist corrosion much better. Straight-line hangers are sometimes required for direct attachment to a bracket arm without the use of a span wire; the type used for this purpose is shown in Fig. 17. Double insulation between the trolley wire and the pole is obtained by the use of the insulating tube *a*, which fits over the bracket arm. The tube is surrounded by the split sleeve *b*, which is clamped up by the bolts *c*. A certain amount of flexibility is obtained, as the main body of the hanger *d* is able to pivot round the bolt *e* which attaches it to the split sleeve.

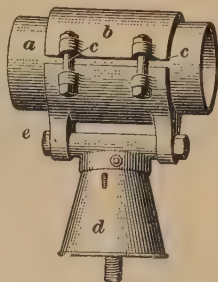


FIG. 17

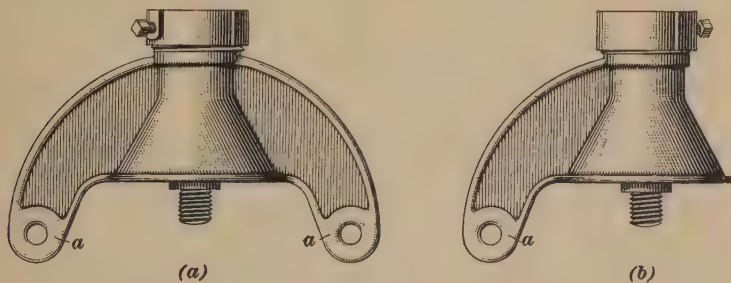


FIG. 18

29. **Double and Single Pull-Offs.**—At curves, where the trolley wire is subjected to considerable side strain, the straight-line hanger is not satisfactory, as it tilts over. Therefore special hangers, known as **double and single pull-offs**, must be used. These are so designed that the direction of the side pull due to

the trolley wire passes through the point of attachment to the span wire. When used on a span wire, these fittings support the weight of the line, but they are often used in positions where they only take side strains. The double pull-off shown in Fig. 18 (a) is provided with two arms *a* for attachment to the span wire; the single pull-off, view (b), has only one arm *a*.

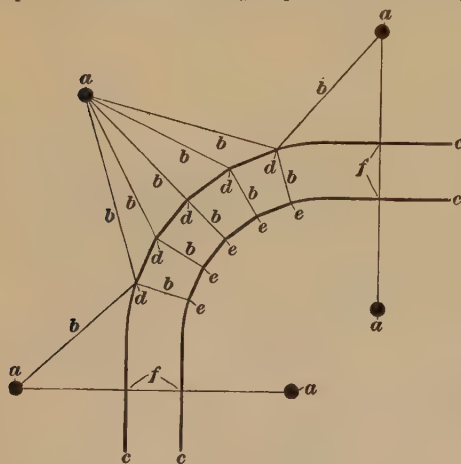


FIG. 19

and single pull-offs *e* on the inside curve. Straight-line hangers are used at the points *f*. The arm of the double pull-off next the pole has to stand the side pull of both trolley wires, while the arm away from the pole has only to stand the pull of one trolley wire.

31. Brooklyn Insulator.—A strain insulator much used for insulating the span wire from the pole, and known as the **Brooklyn insulator**, is shown in Fig. 20. It consists of an insulated bolt *a* similar to that used in straight-line hangers, but tapped out at the end to take an eye-screw *b*, by means of which the tension on the span wire can be adjusted. The head of the insulated bolt is held in the

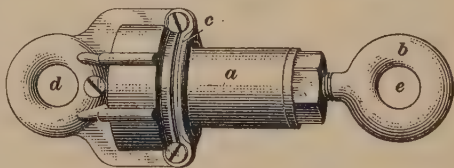


FIG. 20

The internal construction of these pull-offs is identical with that of the straight-line hangers.

30. Method of Using Pull-Offs.—The way in which pull-offs are used in curve work is shown in Fig. 19. The poles are shown at *a*, the pull-off wires at *b*, and the trolley wires at *c*. Double pull-offs *d* are used next to the poles,

casting *c*, which is attached to the pole bracket by a bolt which passes through the eye *d*. The span wire is attached to the other eye *e*. One of these insulators will take up a slack of 3 inches. The standard-size insulator weighs 2 pounds 10 ounces, and the extra-heavy size, 5 pounds 12 ounces.

32. Globe, or Strain, Insulators.—Globe, or strain, insulators, such as those shown in Figs. 21 and 22, are sometimes used instead of Brooklyn insulators on account of their cheapness.

On some systems, it is the practice to use globes at one end of the span and Brooklyns at the other. A form of globe insulator which finds a large

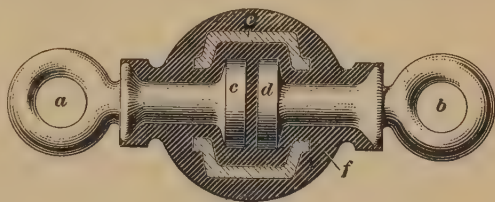
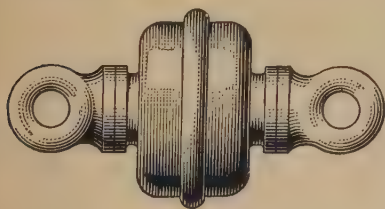
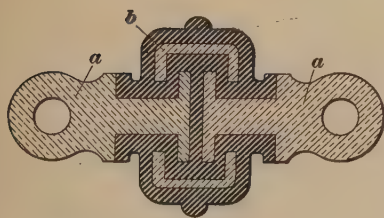


FIG. 21



(a)



(b)

FIG. 22

application consists of two metal eyes *a*, *b*, Fig. 21, that have enlarged ends *c*, *d*. These ends are surrounded by a metal ring *e*, and the whole is insulated by being cast into the ball of hard insulating material *f*. Another type of strain insulator is shown in Fig. 22, (*a*) being the exterior appearance of the insulator and (*b*) a section. The two castings *a* are insulated from each other and from a third casting *b*, which takes the strain. Both of these types are so constructed that, even if the insulating material were to be entirely destroyed, the wires would not fall, because the metal parts are

interlocked. Table V, which gives the breaking load and the breakdown voltage of strain insulators of the Brooklyn and

globe types, shows that they are strong both mechanically and electrically.

33. Insulated Turnbuckle.—The construction of an insulated

TABLE V
BREAKING LOAD AND BREAKDOWN
VOLTAGE OF STRAIN INSULATORS

Type of Insulator	Breaking Stress Pounds	Break-down Voltage
Brooklyn, small . . .	9,000	10,000
Brooklyn, large . . .	18,000	10,000
Globe 2½-inch diameter	6,000	7,000
Globe 3-inch diameter	9,000	10,000

turnbuckle is shown in Fig. 23, (a) being a plan and (b) a sectional elevation. The turnbuckle consists of a link *a* into the opposite ends of which screw two threaded rods *b*, *c*. One rod *b* is furnished with a right-hand thread and the other rod *c*

with a left-hand thread; therefore, turning the link *a* in one direction draws the rods together, and turning it in the other direction

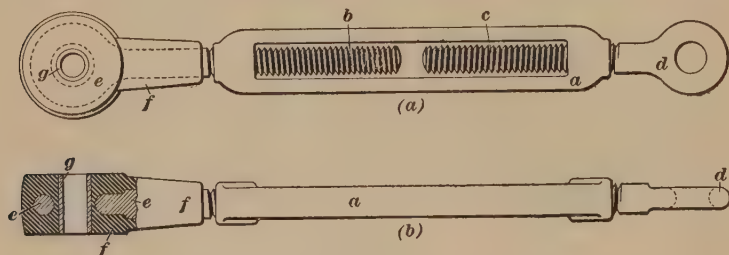


FIG. 23

screws them apart. One rod *c* terminates in an ordinary eye *d*, but the eye *e* attached to the other rod *b* is embedded in insulation *f*. The hole in the insulation at the centre of the eye is furnished with a brass bush *g* to protect the insulation from damage. An insulated turnbuckle is capable of taking up a slack of 6 inches.

34. Reel Insulator.—A type of insulator which is coming into favour for insulating the span wire from the pole is the simple

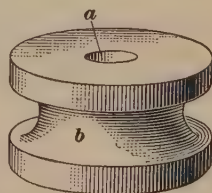
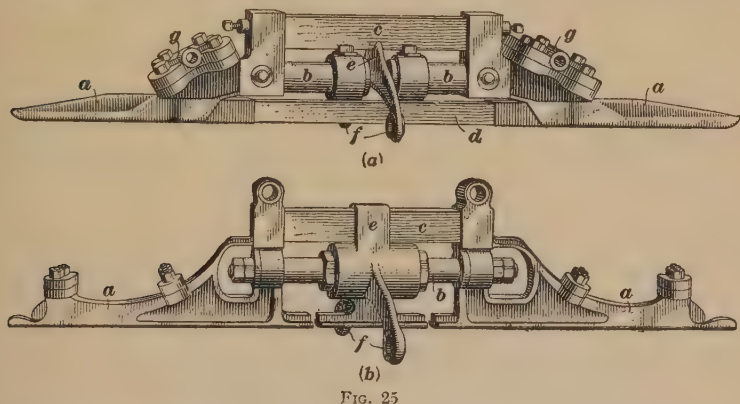


FIG. 24

brownware reel shown in Fig. 24. A bolt passing through the centre hole *a* secures the reel to the bracket arm, and the span wire is fastened round the groove *b*. These insulators are very cheap and their insulating properties do not deteriorate.

35. Section Insulators.—Section insulators are used to divide the overhead line into $\frac{1}{2}$ -mile sections insulated from one another, as required by the Board of Trade. A common design is shown in Fig. 25 (*a*). The trolley wires are attached to the end castings *a* in the same manner as to a splicing ear. These end castings are connected in three places by insulating pieces *b*, *c*, *d*. The part *b* is made up of two insulated bolts of the same type as those used in straight-line hangers. These bolts are screwed



into the end castings and the heads are connected by a coupling *e*. The insulating part *c* is a compression strip of hardwood, and resists the tendency of the strain on the trolley wire to pull the castings together at the top. The coupling *e* has two extensions *f* cast on to it for the attachment of the span wires. The two castings *a* are joined by the strip of hardwood *d*, so that an unbroken and smooth surface is provided on which the trolley wheel can run. The strip *d* is attached to the castings by means of screws, so that it can be easily renewed when worn out. Two terminals for attaching feeder wires are shown at *g*.

In some types of section insulator the wooden strip *d* is done away with, and the trolley wheel runs on an extension piece

cast on to the coupling *e*. This extension piece does not make contact with the end castings, short air gaps being left, over which the trolley wheel jumps. A section insulator of this type is shown in view (*b*), which is lettered similarly to view (*a*).

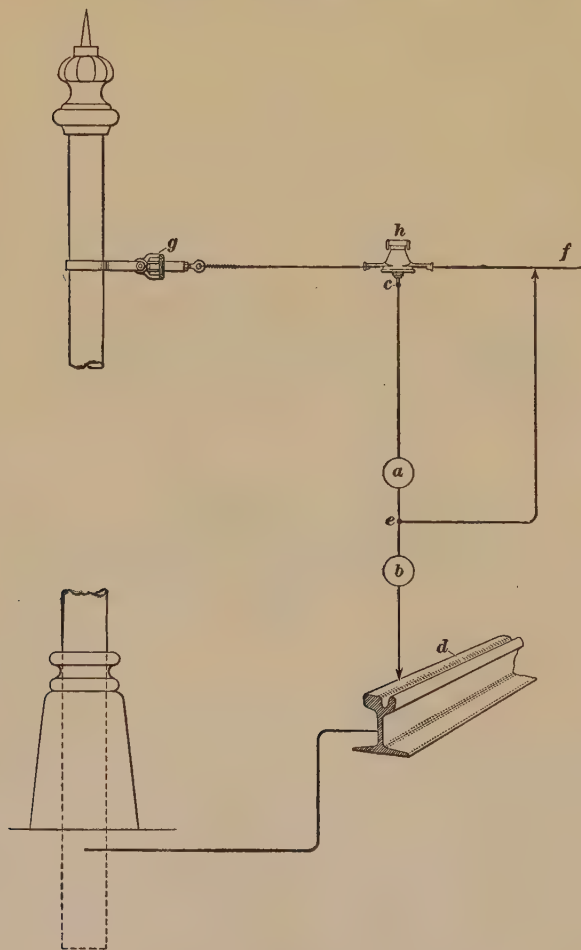


FIG. 26

36. Testing Insulating Fittings.—The Board of Trade regulations require that all overhead insulators shall be inspected and tested once a month. This testing can readily be done by

means of two voltmeters, each reading to 500 volts. These voltmeters *a*, *b*, Fig. 26, are connected in series between the trolley wire *c* and the rail *d*. The middle point *e* between the two voltmeters is connected to the span wire *f*. If the two voltmeters are similar, both will read one-half the line voltage if the insulation of both the strain insulator *g* and the hanger *h* is sound. If the insulation of the strain insulator *g* is defective, there will be a circuit from the span wire *f* to the rail *d* by way of the defective insulator and pole. The voltmeter *b* will therefore be short-circuited and will read zero, while the voltmeter *a* will read the full line pressure. By tracing out the circuit, it will be evident that, if the insulated bolt in the hanger *h* is defective, voltmeter *a* will read zero and voltmeter *b* will read the full line voltage.

37. In order to make these tests rapidly, a contact-maker, known as a **flipper**, is sometimes attached to the trolley arm of the first car to be driven over the route in the morning. The construction and action of this flipper are shown in Fig. 27.

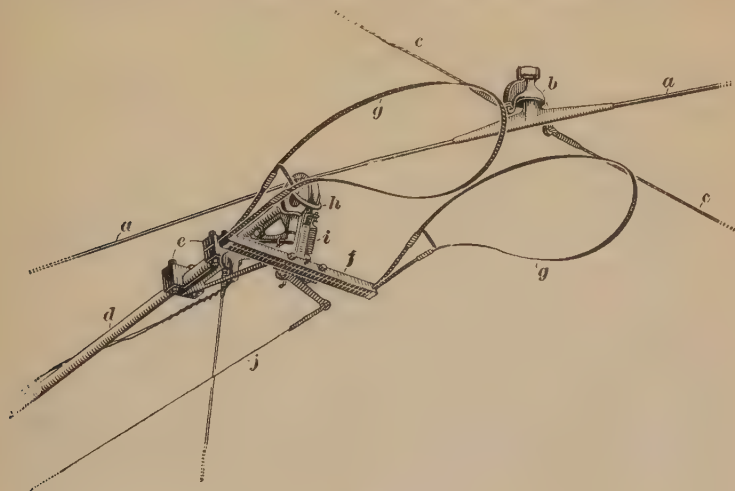


FIG. 27

The trolley wire *a* is supported by the pull-off and ear *b* from the span wire *c*. Fixed to the trolley arm *d* by clamps *e* is a light aluminium framework, to which a wooden rod *f* is attached by means of a pivot passing through its middle point. This

rod carries two loops *g* of thin steel ribbon, and is coupled to the swivelling trolley head by the metal fork *h*, so that it keeps always at right angles to the trolley wire. The rod *f* and steel loops *g* are normally kept in a raised position by the spring *i*, but can be pulled down out of action by the cord *j*. When the steel bows are raised, they *flip* against, or make momentary contact with, each span wire on both sides of the hanger or pull-off.

38. An insulated wire is carried down the trolley arm *d*, Fig. 27, in order to connect the steel loops *g* to the voltmeter inside the car. It is not usual to employ two voltmeters and test both strain insulators and hangers at once; one set of insulators is tested as the car runs out, and the other set on the return journey. The voltmeter is provided with a simple change-

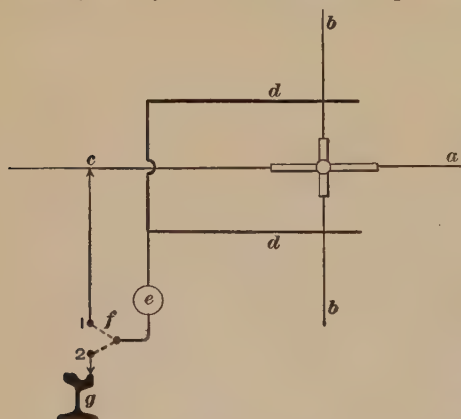


FIG. 28

over switch, by means of which either set of insulators can be tested without altering connecting wires. The connections are shown in diagrammatic form in Fig. 28, where *a* is the trolley wire, *b* the span wire, *c* the trolley wheel, *d* the steel contact loops, *e* the voltmeter, *f* the change-over switch, and *g* the track

rail. When the change-over switch *f* is on contact 1, the voltmeter *e* will not deflect unless the strain insulator is faulty, and when the switch is on contact 2, the voltmeter deflects when the hanger or pull-off is faulty. On account of the exceedingly short duration of the contact between the span wire and contact loops when the car is running at 7 or 8 miles per hour, the voltmeter used must be sensitive in order to give any appreciable deflection in the time. It is usual to employ a voltmeter which will give a deflection right over its scale with a pressure of one-fifth of the full line voltage.

FROGS AND CROSSINGS

39. Necessity for Frogs.—At the point where one line branches from another, overhead switches, or *frogs*, are used to guide the trolley wheel from one wire to the other. The construction of these frogs depends on whether the holder of the trolley wheel which is used to collect the current is rigidly attached to the trolley pole, or is free to move about a vertical axis while the trolley pole remains stationary. The former type of trolley wheel and holder is known as a *fixed trolley head*, and the latter as a *swivelling trolley head*. When fixed trolley heads are used,

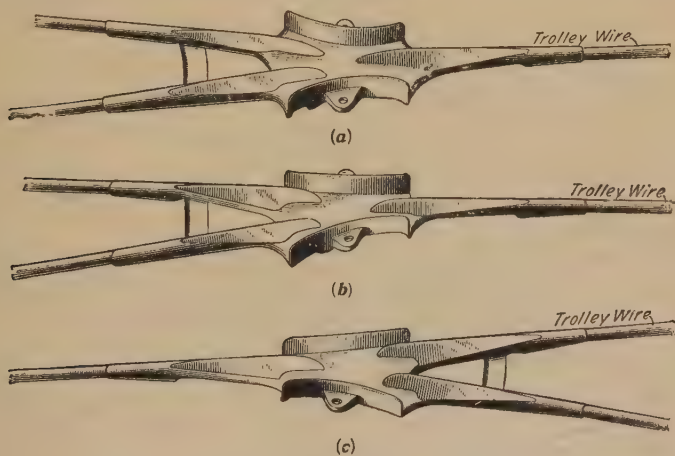


FIG. 29

the system must be arranged for centre-running, and the trolley pole and wheel will follow the car. With a side-running system, it is necessary to use swivelling trolley heads, and unless the frogs on the overhead work are specially constructed, it is quite possible that the car will take one direction and the trolley wheel the other.

40. Frogs for Fixed Trolley Heads.—In Fig. 29 (a) is shown the under side of a simple two-way V frog of a type that is largely used; (b) is a right-hand frog and (c) a left-hand frog. In these frogs the trolley wire is soldered into the ears. Fig. 30 shows

a **V** frog in its natural position. In this case the trolley wire is held by clamps *b*, and no solder is necessary. The span wire is attached to the ears *a*.

41. As frogs must be placed correctly with relation to the track, mechanical fastenings for the wires are desirable because they allow the frog to be adjusted to the position that gives the

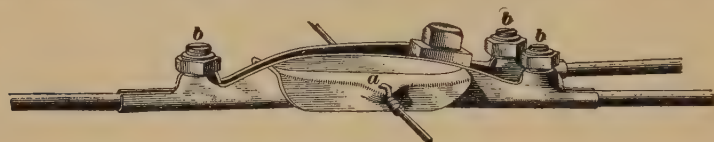


FIG. 30

best results. The satisfaction that any frog will give depends a great deal on how it is put up. If level, the trolley wheel is very likely to follow the direction of the car, but if allowed to sag on one side, it will always give trouble by throwing the trolley wheel off the wire. The position for the frog may be found by the method shown in Fig. 31, where *a* and *b* are the main-line tracks, *c* and *d* the branch-line tracks, *a'* *b'* the main trolley

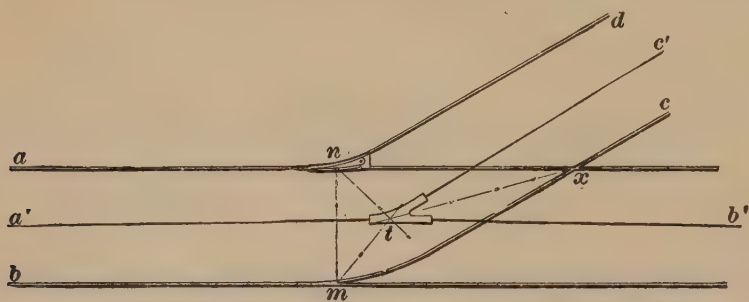


FIG. 31

wire, and *tc'* the branch trolley wire. The centre of the triangle *n x m* will be at a point *t* where the lines bisecting each angle meet; this determines the position of the frog. It will be a little removed from the centre lines of the tracks. In practice it is often found necessary to adjust a frog after it has been put up. Lateral adjustment can be obtained by means of the turnbuckles attached to the span wires. When a frog is first connected, the trolley wire should be left long and the end coiled

up on top of the frog, so that the latter can be shifted forwards or backwards in case such adjustment is necessary.

42. **Frogs for Swivelling Trolley Heads.**—For swivelling trolley heads, two types of frogs, known as **trailing frogs** and

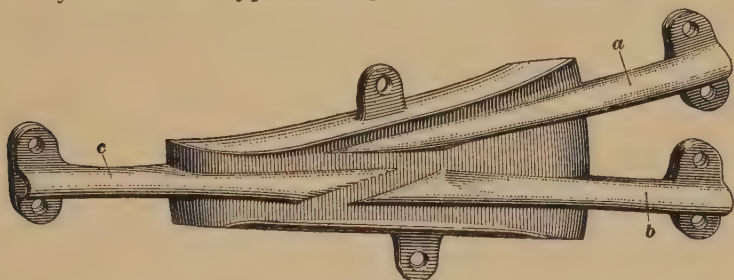
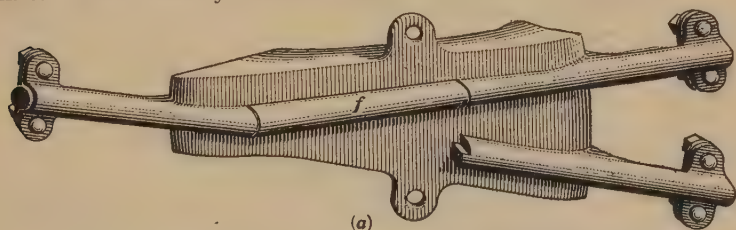
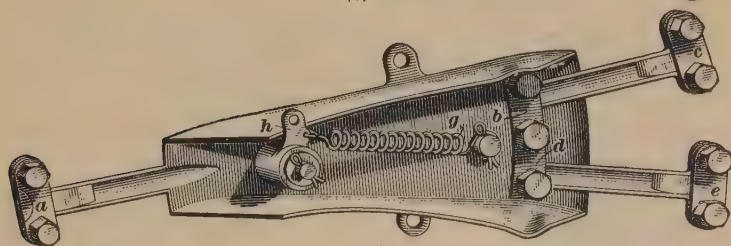


FIG. 32

movable, or mechanical, frogs, are used. Trailing frogs are used where the trolley wheel has to pass from a branch on to the main line. There is only one wire that the trolley wheel can run on



(a)



(b)

FIG. 33

to. In construction it resembles frogs for fixed trolley heads, and is shown in Fig. 32. The trolley wheel can pass from either branch line *a*, *b* to the main line *c*. The chief difference between this type of frog and that used for fixed trolley heads is that the

open space in the centre of the frog is much larger in the latter type.

43. Movable, or mechanical, frogs are used where the main trolley divides into two or more branches, and are fitted with a movable tongue to guide the wheel on to the proper wire. A two-way mechanical frog is shown in Fig. 33. The tongue is operated by a steel wire suitably insulated and carried down the nearest pole to the footpath, from which position it is operated by the conductor of the car or a special pointsman. View (a) shows the running face, and view (b) the method of controlling the movable tongue. One trolley wire passes straight through the frog and is held by the clamps *a*, *b*, and *c*; the branch wire is secured by the clamps *d* and *e*. The tongue *f* of the frog is held in the branch position by the spring *g*. The thin steel wire for turning the tongue to the straight-through position is attached to the lever *h*. In some systems the frog is worked automatically by the trolley pole of the car going round the curve operating a lever which moves the tongue; in other systems a special contact is provided on the controller of the car, which energizes an electromagnet controlling the tongue of the frog.

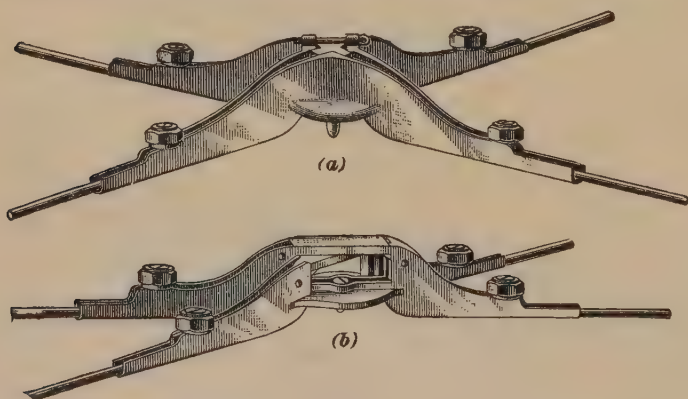


FIG. 34

44. Crossings.—At the point of intersection of two trolley lines, a device called a **crossing**, or **cross-over**, is used. Two common forms are shown in Fig. 34. That shown in (a) is used where the two lines cross at right angles, and that in (b) where

they cross at an acute angle. Crossings of this type do not insulate from each other the two intersecting trolley wires, and on this account they are called **uninsulated crossings**.

45. As trolley wires must be capable of division into $\frac{1}{2}$ -mile sections, when uninsulated crossings are employed, section insulators must be used in conjunction with them, as shown in

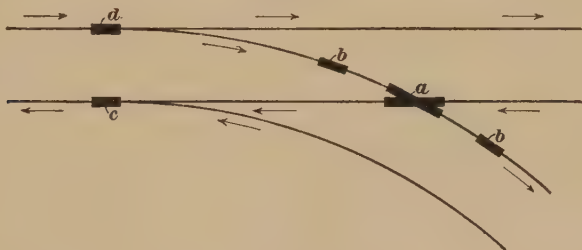


FIG. 35

Fig. 35, where *a* is the uninsulated crossing, and *b* the section insulators. A fixed frog is used at *c*, and a movable one at *d*. The directions of travel of the trolley wheels on the wires are shown by the arrows.

46. Where the angle of crossing is between 75° and 90° , insulated crossings can be used. A crossing of this type is

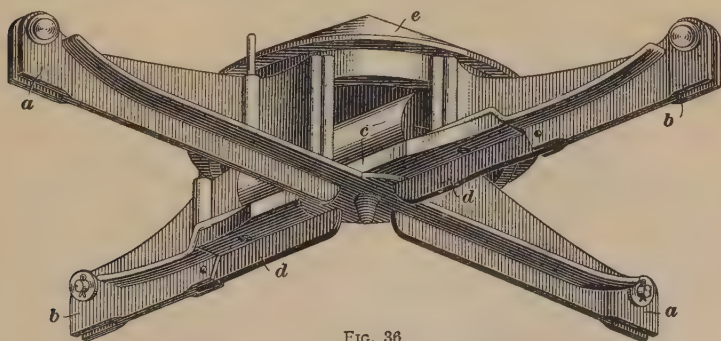


FIG. 36

shown in Fig. 36. The ends of one trolley line are attached to the lugs *a*, which form part of one continuous casting. The ends of the other trolley line go to the lugs *b*, which are insulated from each other by the wood or fibre insulation *c*. These lugs *b*

are provided with extension pieces *d* of insulating material on which the trolley wheel runs. The whole is protected by the fibre cap *e*. These crossings are only suitable for large angles at the intersection of the trolley wires; for narrow angles, uninsulated crossings in conjunction with section insulators must be used.

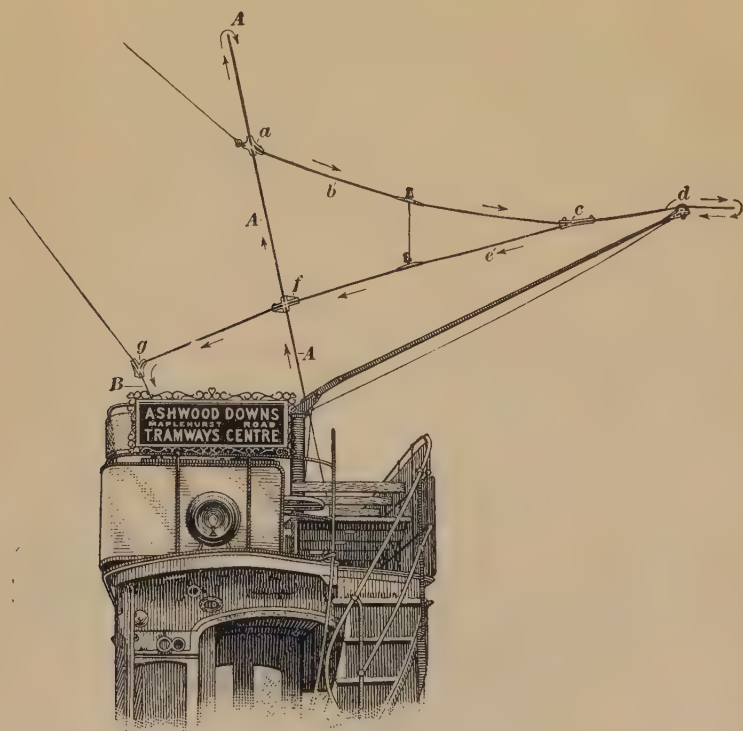


FIG. 37

47. Trolley-Arm Reverser.—When a car reaches a terminus, it is necessary to change the trolley arm from one wire to the other and to turn it round so that it trails behind the car. With the type of overhead construction usually adopted, this is effected by pulling down the trolley arm by means of a rope, swinging it round, and allowing it to rise again with the trolley wheel under the correct wire. If the terminus is not well lighted

at night, it is often a difficult matter to get the wheel on the wire, and in addition involves leaving the car in darkness while the change is made.

48. To avoid these disadvantages, a special combination of frogs and crossings, as shown in Fig. 37, is sometimes adopted to reverse the trolley arm. This arrangement needs no attention from the conductor and the lights on the car do not go out while the trolley is reversing. The car, in coming into the terminus (toward the observer), uses line *A* until it passes the fitting *a*. On being reversed, the car travels away from the observer, and, passing over fitting *a* in the opposite direction, the trolley wheel is shunted by it on to the wire *b*, from which it passes over the fitting *c* on to the wire *d*. The trolley arm is then reaching out to its full extent, at right angles to the car. As the car proceeds, the trolley wheel returns along the wire *d* and again crosses fitting *c*, which shunts it on to wire *e*. It runs over the crossing *f*, and is turned by fitting *g* on to the trolley wire *B*. The trolley arm is then trailing in its correct position for the return journey.

ERECTION OF OVERHEAD WORK

TOWER WAGONS

49. **Construction.**—For erecting and repairing the trolley wire and overhead fittings, a **tower wagon** is employed. This consists of a platform raised on a staging, the whole being mounted on a special wagon, so that work may be done on the overhead wire and equipment without the use of ladders. The height of the platform is often adjustable by means of gearing, so that the work may be done in the most convenient way. In some types of tower wagon, the tower is mounted on a wagon drawn by horses, and in others it is mounted on a motor wagon. The latter type, shown in Fig. 38, is very useful in the case of breakdown, where repairs are urgently necessary. The height of the working platform *a* can be adjusted by means of the gearing *b*.

In many tower wagons, the base of the tower is filled in with

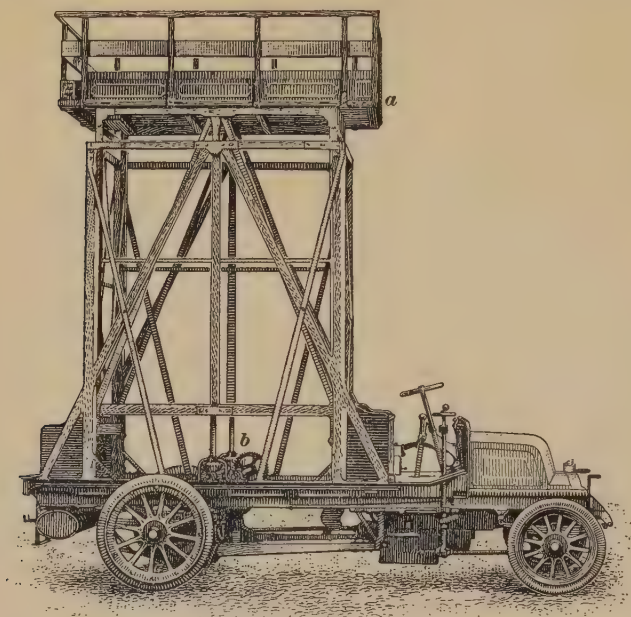


FIG. 38

tool boxes, in which are carried the tools and spare fittings, so that repairs can be executed in the shortest possible time.

SUSPENSION OF SPAN AND TROLLEY WIRES

50. **Suspension of Span Wire.**—After the poles have been erected and allowed to set, the span wire is stretched into position, the necessary tension being obtained by means of a device called a **screw coupling**, or **pulling jack**, which is attached to the wire by a special clamp, known as a **come-along clamp**. A screw coupling, or pulling jack, shown in Fig. 39 (a), is similar in construction to a turnbuckle, but much more massive. The two screw hooks *a*, *b* are provided with right- and left-hand screw threads and are drawn together by turning the rod *c*. The

ends of the rod are provided with flattened surfaces *d* to enable them to be gripped by a wrench.

A come-along clamp, shown in Fig. 39 (b), is composed of three steel links *a*, *b*, *c* pivoted together at *d* and *e*. The wire to be gripped is inserted between the jaw on one link *b* and a projection on another link *c*. When a pull is exerted on the third link *a* by means of a rope passing through the eye, the

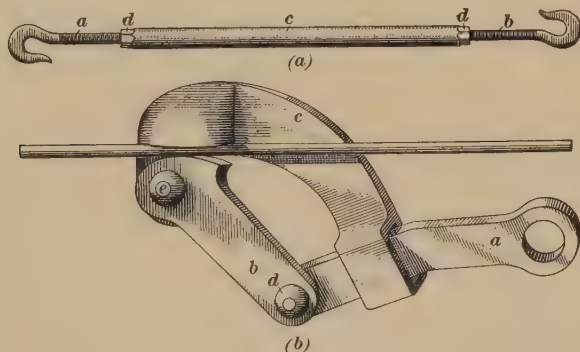


FIG. 39

jaw of link *b* moves upwards and firmly clamps the wire. The greater the pull on the link *a*, the more firmly is the wire gripped. For erecting the very short span wires often used with the bracket-arm construction, these tools are not required, sufficient tension being obtainable by the use of an insulated turnbuckle or Brooklyn strain insulator.

51. Suspension of Trolley Wire.—When the span wires are in position, the trolley wire is suspended. This is usually supplied on drums, each holding $\frac{1}{2}$ or 1 mile of wire, which are mounted on a special reel wagon, which precedes the tower wagon by about 40 yards. The end of the trolley wire having been securely anchored to a terminal post, the wire is passed over the tower wagon and both tower wagon and reel wagon move forwards, the tower wagon stopping at each cross-span and attaching the wire temporarily with a binder or an **S**-shaped iron hook to the span wire or bracket arm. When the wire is all run out, it is stretched to the desired tension by means of

pulley blocks or a screw coupling, used in conjunction with a come-along clamp. At curves, temporary anchor wires are attached, and the whole section is tightened and adjusted several times before the permanent attachment of the trolley wire to its supports is commenced.

52. Permanent attachment is usually made first at curves, the trolley wire being held in a soldering clamp, the construction

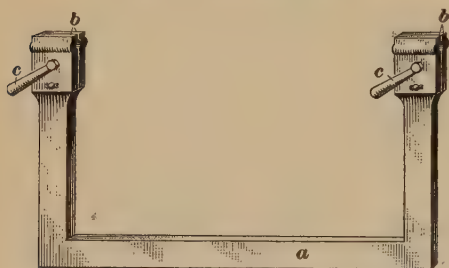


FIG. 40

of which is shown in Fig. 40. This clamp consists of an iron frame *a* provided with jaws *b*, which can be made to clamp the wire by means of the handles *c*. The clamp is usually attached to the trolley wire with the bar *a* above

the wire, which is given a half twist by bringing the clamp into the position shown in Fig. 40. The wire is then well cleaned and tinned with solder, and the ear soldered to it with the screwed stem downwards. This allows the solder to be easily poured into the ear. The joint is then carefully smoothed off with a fine file and emery paper, and the clamp is returned to its first position, so that the stem of the ear is upwards, ready for attachment to the hanger or pull-off.

53. Tension on Trolley Wire.—In putting up trolley wire, judgment must be used regarding the tension put on it. Thus, wire strung in hot weather must be allowed more sag than that put up in cold weather, otherwise the contraction will put severe strains not only on the trolley wire itself, but on the whole overhead construction. A range of 45° C. between summer and winter temperatures will correspond to a variation of nearly 4 feet per mile in the length of the trolley wire. For a 120-foot span of No. 0 B. & S. wire, put up with a tension of 2,000 pounds, the sag at the centre of the span will be 3.6 inches; for a tension of 1,500 pounds, 5 inches; for 750 pounds, 9.5 inches; for 500 pounds, 15 inches. Dawson recommends, as a safe

allowance for localities where the temperature does not fall below about -10°C. , a sag equal to three-fourths of 1 per cent. of the span when the wire is strung at the ordinary temperature of from 15° to 18°C. Thus, for a 120-foot span, a sag of about 10.8 inches would be allowed, and in the warmest weather the sag would not exceed 15 inches.

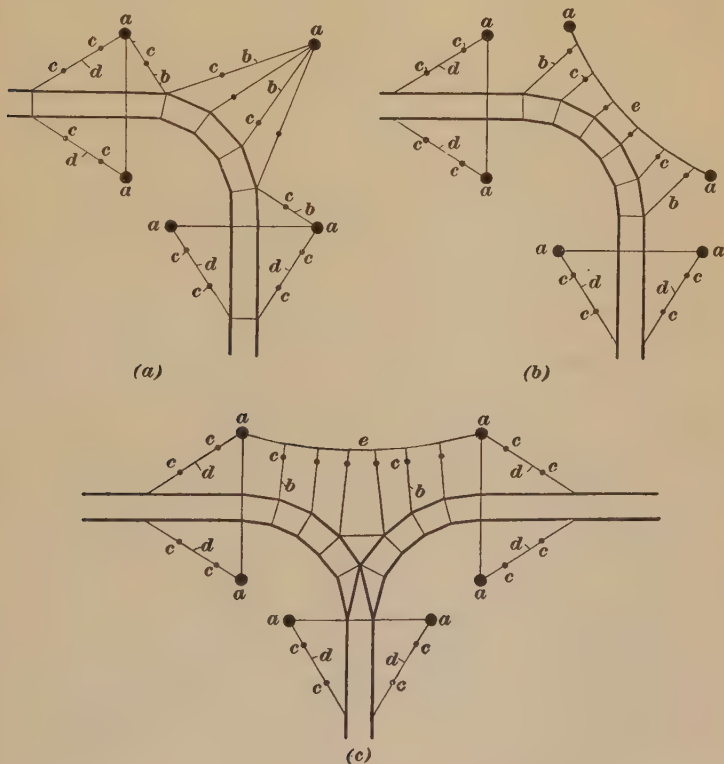


FIG. 41

54. Construction at Curves.—The methods of securing the trolley wires at curves are shown in Fig. 41, in which *a* are the poles, *b* the pull-off wires, and *c* the strain insulators. In (*a*), the trolley wires are anchored on each side of the curve by anchor ears, which are attached to the anchor wires *d*. View (*b*) shows another arrangement, in which the pull-off wires *b* are attached

to a stout span wire e stretched between the poles a, a . The anchoring arrangement is the same as in view (a). In view (c) is shown the arrangement adopted at a double curve.

55. Offset in Trolley Wire.—When erecting an underrunning system for use with a fixed trolley head on curves, the trolley wire is not suspended exactly over the centre line of the track, but is shifted toward the inside rail by a distance that depends on the radius of the curve, the height of the wire, and the length of the trolley arm. This departure from the centre line of the track is shown in Fig. 42, where the curve r is the centre line of the rails and t the path of the trolley wire. The amount of offset measured at the middle of a 90° curve at the point indicated by the

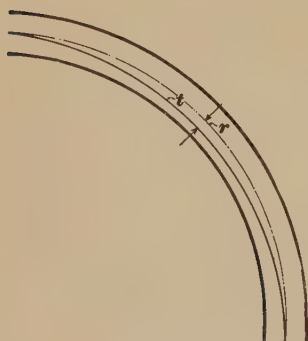


FIG. 42

arrows in Fig. 42 should be approximately as shown in Table VI. The object of the offset is to allow the trolley wheel to lie closely to the wire, which it would not do if the wire followed the centre line of the track, as the wheel would lie diagonally across

TABLE VI
OFFSET IN TROLLEY WIRE

Radius of Curve Feet	Offset Inches	Radius of Curve Feet	Offset Inches
40	16	100	6
50	13	120	5
60	12	150	4
80	8	200	3

the wire and cause a large amount of wear on curves. Where a swivelling trolley is used, considerable latitude may be allowed, and the trolley wire may be several feet from the centre line of the rails on curves.

ELECTRICAL CONSIDERATIONS

SUPPLY AND CONTROL OF CURRENT TO TROLLEY WIRES

FEEDERS

56. The **feeder system** includes all the cables necessary to distribute the current from the generating station or substation to the working conductors; in the overhead system it consists of the trolley wires and the track rails. In compliance with the Board of Trade regulations, the trolley wire is divided into $\frac{1}{2}$ -mile sections insulated from one another, and the connection with the feeder system is usually made at the centre or ends of each section.

In the conduit system, which has an insulated return, the negative feeders are duplicates of the positive feeders; but in the overhead system, which has an earthed return, the negative feeder system differs from the positive, and requires separate consideration. In Great Britain, feeder cables are laid underground, but in America, on the Continent, and in the Colonies they are run overhead. They usually follow the line of track, but considerable saving may sometimes be effected by taking a short cut between the power station and the feeding point; this means not only a saving in the cost of the feeder, but also in the watts lost in transmission. Any of the standard types of underground mains may be used for feeders.

57. **Feeder Pillars.**—The positive feeder terminates on a small switchboard placed in a cast-iron box, called a **feeder**, or **switch**, **pillar**, which is placed on the footpath near the point at which connection is to be made to the trolley wire. The short feeders connecting the main feeder with the trolley wire are

called line taps, or side feed-cables. They are usually drawn inside one of the poles used for supporting the trolley wire; and from the pole they pass along either the bracket arm or span wire to a feeder ear attached to the overhead wire. These line taps are connected to a feeder bus-bar in the switch pillar through trolley switches, which are used when necessary for cutting the current off the overhead wire.

A typical tramway feeder pillar, arranged for feeding at the section insulators, is shown in Fig. 43, (a) being the front view

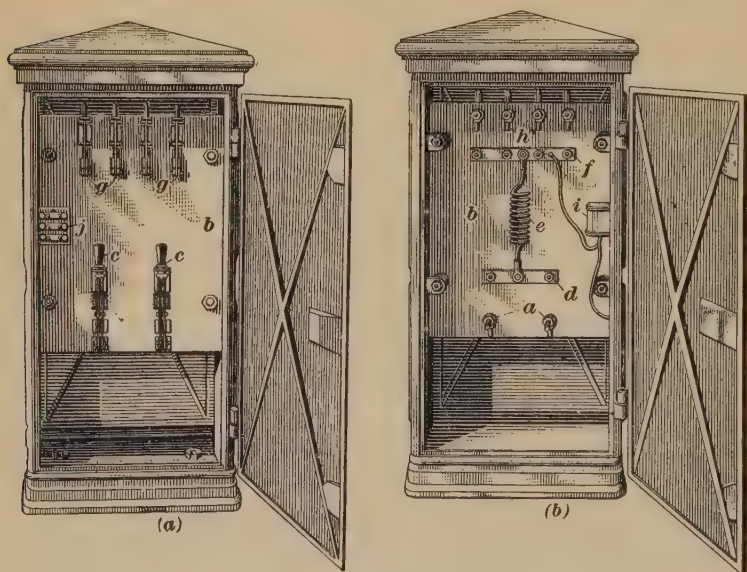


FIG. 43

and (b) the back view. The incoming feeders from the power station are connected to the terminals *a*, which pass through the slate slab *b* to the lower terminals of the switches *c*. When these switches are closed, they connect the feeders to the bus-bar *d*, which is connected through the choking coil *e* of the lightning arrester to the bus-bar *f*. The bottom contacts of the trolley switches *g* are connected to this bus-bar *f*, and the top contacts are provided with sockets *h*, into which the side feed-cables are sweated. Any side feed-cable can thus be connected

to the feeder bus-bar by closing its switch. A lightning arrester *i* is connected to the bus-bar *f*, while a terminal board *j* is provided for telephone or pilot wires. The feeder pillar is fitted with doors at front and back, so that the switches and connections are easily accessible. The doors are kept locked, so that no unauthorized persons can have access to the connections.

58. Methods of Feeding.—The simplest method of feeding is to connect the trolley wires with the bus-bars in the power station *a*, Fig. 44, by means of short feeders *b*₁, *b*₂, and provide switches *d*₁, *d*₂, etc., at each section insulator, the overhead wire serving the purpose of both feeder and working conductor. Such a method is of course only suitable for a light service. The switch boxes *d*₁, *d*₂, *d*₃, *d*₄, *d*₅, *d*₆ are fixed to the poles and are connected to the trolley wires by means of the side feed-cables *e*, *e*.

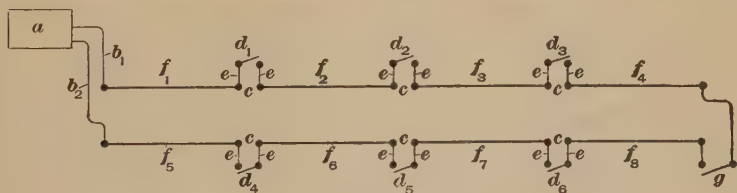


FIG. 44

When a switch *d*₁ is closed, the current is conveyed from the section *f*₁ to the section *f*₂. A switch must also be placed at the end *g* to connect the two wires in parallel, so as to reduce the drop in the line. This switch is also necessary if it is desired to cut the current off one $\frac{1}{2}$ -mile section; with no switch at *g*, if the switch *d*₁ were opened, the current would be cut off the three sections *f*₂, *f*₃, and *f*₄, whereas, with a switch at *g*, the current could be cut off the section *f*₂ by opening the switches *d*₁ and *d*₂.

59. Where the drop in the line would be too great to adopt the method just given, the arrangement shown in Fig. 45 might be employed. In this case a feeder runs from the power station *a* to the point *h*, feeding the sections *f*₃ and *f*₇. The current will be conveyed to the next sections *f*₄ and *f*₈ by means of the section switches *d*₃, *d*₆. The additional feeder might be connected to work in parallel with the short feeders *b*₁ and *b*₂ by closing section

switches d_2 and d_5 , or it might be insulated from them at h , and the short feeders b_1, b_2 left to deal with the sections of trolley wire f_1, f_2, f_5, f_6 . Under ordinary service conditions, it is advisable to separate the feeders in order to more easily locate defects,

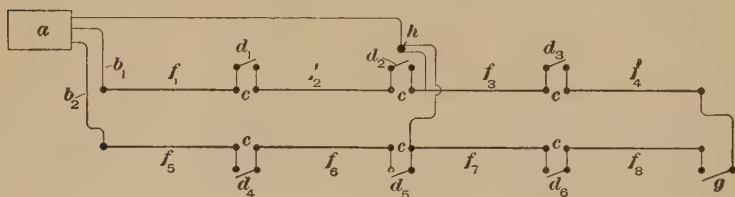


FIG. 45

but on special occasions of heavy load it should be possible to join the feeders in parallel.

60. In the case of a very heavy service, it might be necessary to run distributing cables from the main feeders to other feeding points, so as to reduce the drop, in volts, in the trolley wire. In the arrangement just shown, the feeder is supplying the trolley wire at the section insulators, but this arrangement is not always adopted; the feeder and distributor boxes are sometimes placed at the centre of the $\frac{1}{2}$ -mile sections. In Fig. 46 (a) is shown a typical $1\frac{1}{2}$ miles of tramway fed from one feeder, the side feed-cables being connected to the section insulators; view (b) shows a similar route with the side feeds connected to the centre of the sections. In each case, a, a', b, b', c, c' are the three $\frac{1}{2}$ -mile sections of double-track trolley wire, which are supplied by the feeder d . The feeder switches are lettered e , the interconnecting switches f , the distributor switches g , and the trolley switches h . The distributing cables are shown at i , and the section insulators are indicated by the openings j in the trolley line.

For economy in transmission, the method of feeding into the section insulators is preferable, for the trolley wire is in parallel with the distributing cable and so helps in distributing the current to the next section. The advantages of feeding into the centres of the sections are that the number of side feed-cables and trolley switches is reduced by one-half, and consequently the trolley switches are more easily understood and handled by

non-technical traffic inspectors. In order to have the feeder *d* disconnected from the adjacent feeders when it is feeding into the section insulators, it is necessary to leave open both centre trolley switches and the interconnecting switch in each end feeder

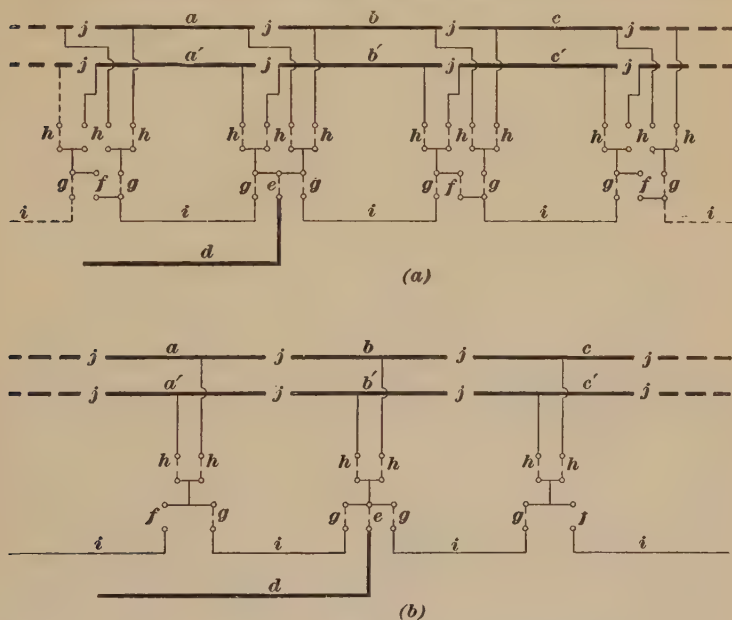


FIG. 46

pillar. When feeding into the centre of the circuit, it is only necessary to leave open the interconnecting switch *f* in each end feeder pillar to disconnect feeder *d* from the adjacent ones. If the various feeders are to be connected through fuses, the fuses will be inserted in place of the interconnecting switches.

POSITIVE BOOSTERS

61. Functions of Positive Boosters.—When some of the sections of a tramway are situated a considerable distance from the power house, it is necessary, in order to avoid the use of a large amount of copper in the feeders, to use feeders of small cross-section, and to compensate for the voltage drop in them by the

use of a **positive booster**. A positive booster is a generator connected in series with the feeder or feeders on which the voltage is to be raised, in such manner that the voltage that it generates is added to that of the main generators, thus increasing the voltage applied to the feeders by the amount of the pressure generated by the booster. In Fig. 47, *a* represents the armature of the main generator and *b* the booster armature. Short feeders supplying sections close to the power house are connected to the + bus-bar of the generator in the usual manner, and long feeders are connected to the + bus-bar through the booster.

62. For tramway work, boosters are nearly always of the series type; that is, the field winding is connected in series with the armature. The machines are so designed that the voltage generated increases in proportion to the current that passes

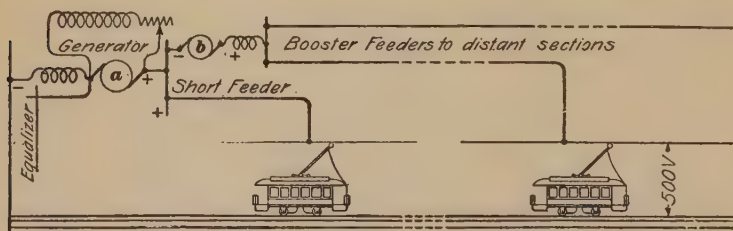


FIG. 47

through them. Thus, when the load on the long-distance feeders is light, the booster voltage is low because the field is weak. When a heavy load comes on, the booster voltage increases and automatically compensates for the drop in the long feeders supplied through the booster. If the booster were shunt- or compound-wound, and thus generated a practically constant voltage regardless of the current supplied over the feeders, an excessive voltage would be applied to the cars at light loads because there would then be little loss in the line to take up the booster voltage.

63. **Methods of Driving Boosters.**—Boosters are nearly always driven by means of shunt-wound motors, which run at a practically constant speed. They can also be driven by steam engines or any other convenient source of power, but in most

tramway stations it is very convenient to use shunt motors supplied from the mains. Boosters do not differ in their general construction from other direct-current generators, except that their commutators are often longer than on standard generators on account of the large current that they carry in proportion to their size.

64. Output of Boosters.—The output of a booster, in watts, is equal to the product of the number of amperes passed through the booster and the number of volts by which the pressure is raised. Thus, if a booster carries 600 amperes, and if when this current is passed through it 100 volts is generated, the output of the booster is $600 \times 100 = 60,000$ watts, or 60 kilowatts. If the current dropped to 300 amperes, the voltage generated would, since the booster is series-wound, drop to about half the full-load voltage, that is, to 50 volts, and the output would then be $300 \times 50 = 15,000$ watts, or 15 kilowatts. Thus, the loss in the line is compensated for automatically and the voltage at the cars remains nearly constant notwithstanding fluctuations in load.

The booster output for any given case will depend on the current to be carried by the feeders that require boosting, and also on their resistance. In Great Britain, feeders of any great length are seldom used, as large tramway systems are supplied from substations, to which power is transmitted by high-tension alternating current. The alternating current is converted to direct current in the substation, which supplies a comparatively small area. A series booster is often provided with a *diverter*, that is, an adjustable resistance in parallel with the field winding, which can be used to divert some of the current from the winding, and thus reduce the voltage generated by the booster.

65. Booster Connections.—A booster must always be connected in series with the feeder or group of feeders in such manner that its voltage will be added to that of the main generators. Thus, the — terminal of the booster must be connected to the + bus-bar of the generator. Fig. 48 shows a plan of connections for a motor-driven booster. The main generators 1, 2, 3 are connected to the + bus-bar in the usual manner,

and the + bus-bar is connected to the — booster bus-bar through switch *a*. Each feeder is provided with a double-throw single-pole switch *b*, by means of which it can be connected either to the main + bus-bar or to the + bus-bar of the booster. As indicated by the dotted lines, the long feeders *A, B* are connected to the booster, while the short feeder *C* is supplied with

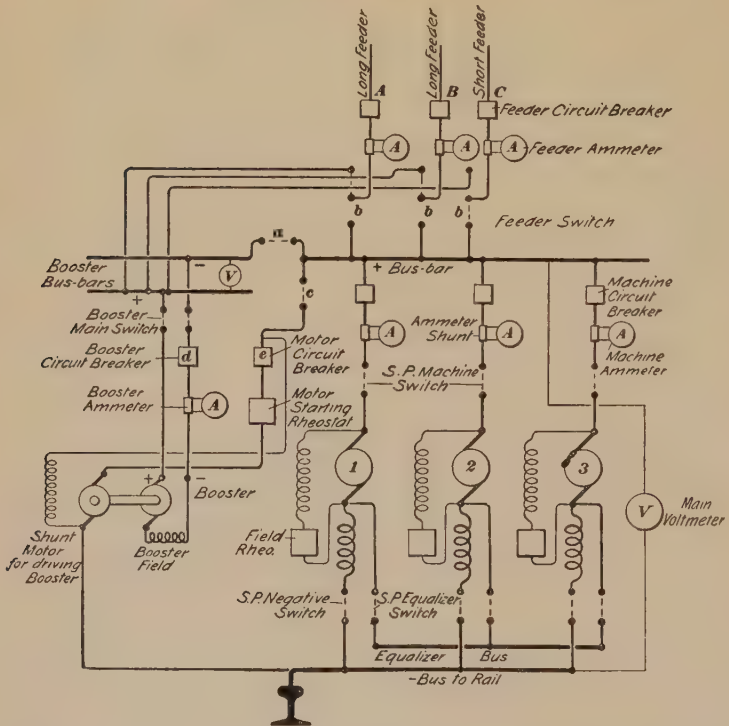


FIG. 48

current directly from the main generator. The booster is driven by a shunt motor supplied with current from the main generators, and equipped with a circuit-breaker and starting rheostat. The booster is connected to the booster bus-bars through an ammeter, circuit-breaker, and double-pole main switch.

66. By following out the connections in Fig. 48, they will be found to be equivalent to the elementary connections in Fig. 47.

All current supplied to feeders *A* and *B* passes through the booster, and the voltage applied to them is increased by an amount proportional to the current. The motor circuit-breaker should be arranged so that in case it opens the motor circuit the current will also be cut off from the booster. The simplest way of doing this is to mount the two circuit-breakers *d*, *e* side by side and have them interlocked, so that when the motor circuit-breaker *e* flies out, the booster circuit-breaker *d* will also open. They should also be arranged so that the booster circuit-breaker *d* cannot be closed until after the motor has been started. If current were cut off from the motor, but not from the booster, the latter would be driven as a series motor, and an unloaded series motor on a constant-potential circuit will race badly. If, therefore, the current is not shut off promptly damage may result. The diagram in Fig. 48 shows how boosters are connected when not worked in conjunction with a storage battery. In a large number of substations, however, storage batteries are employed.

ECONOMICAL USE OF FEEDERS

GENERAL CONSIDERATIONS

67. Distribution of Load.—It is impossible to lay down general rules, for calculating the most economical amount of copper to install and the best method of disposing of that copper to meet the requirements of a given tramway service, that will apply to all cases and conditions. The present practice of dividing the line into insulated sections has, however, simplified the work of calculation, because each section can be considered as an independent line governed by its own local conditions of load. If these conditions could in any case be laid down with certainty, the problem for any particular case would be solved; but that solution would be of little use to the engineer for application to other cases, because it is almost impossible to find any two systems, or even any two sections of the same system, that have the same conditions of load, and therefore require the same distribution of copper. During one part of the day the

heaviest load might be on one part of the line, and later in the day it might be on a section several miles away.

68. In addition to this, there may take place gradually a general shifting of the load more serious than a daily or weekly change, due, possibly, to changes of attractions from one end of the line to the other, or by a shift in the field of suburban improvements. Although the system may be designed in such a way that it meets satisfactorily almost every requirement of the present service, subsequent changes, such as the development of suburban property, may throw it completely out of balance. The only thing to do then is to install new feeders where they are needed. It is now a well-known fact that it is not economical to spend too much in cables, although they may be placed with good judgment from an electrical point of view, and successfully fulfil their function of raising the voltage to its normal value at the desired point. Cables are expensive, and in the effort to lessen the loss in the line, it is an easy matter to spend so much on them that a condition arises when the money invested in cables might be more profitably invested in other ways, as, for example, in the installation of boosters or storage batteries.

69. **Installation of Feeders.**—The points that must be kept in view when considering the installation of new feeders are as follows: By reducing voltage drop, a certain amount of energy is saved, and the saving in watts or horsepower can be approximately calculated. From a knowledge of what it costs to produce a unit of energy at the power station, the direct saving effected by the increase of feeders can be at once obtained, and by knowing the cost of the additional cables installed, including the cost of construction, the interest on the cost of the copper may be computed. A certain amount must also be allowed for depreciation. Thus, if the life of a cable is 10 years, one-tenth of the difference between the first cost of the cable and its value when replaced must be set aside each year to provide for its replacement. The rule, that it pays to install more feeders if the cost of the watts saved in a year exceeds a year's interest on the cost of the additional feeders installed, together with the allowance

for depreciation, is one that should always be kept in mind. It must not be forgotten, however, that the above limiting condition expressed in the form of an equation (interest on the cost + depreciation = value of energy saved) does not include all the elements that modify the equation.

70. When the feeding system is improved, it brings about a saving in a direct way by reducing the loss in the line and also effects a saving in an indirect way by keeping up the voltage, and thereby increasing the efficiency and speed at which the cars run. This not only decreases the number of cars necessary to conform to the conditions of a given time table, but by improving the service it attracts travel, especially in cases where there is competition. Even in cases where there is no competition, an improvement in the service draws passengers.

Let A = annual interest on cost of feeder ;

B = annual allowance for depreciation ;

C = value of energy saved, per annum ;

D = increase in money taken, due to traffic improvement.

Then, the proper balance is reached when

$$A + B = C + D$$

EXAMPLES OF FEEDER CALCULATIONS

71. **Drop in Feeders.**—In the transmission of current for electric tramways, as in other cases of electric transmission, the loss or drop in the line is usually limited. If the loss is large, a comparatively high-resistance line with a corresponding small amount of copper can be used, but a large line drop means a low voltage at the cars unless the voltage at the station is automatically increased as the load increases. Low line voltage makes it hard for the cars to maintain their schedule time, thus giving a bad service. It is seldom that the average drop is less than 10 per cent. (50 volts), and in some cases it runs higher than this ; if feeding is accomplished through boosters, the line drop may be as great as 100 volts.

72. The weight of the rail is fixed by traffic considerations, and, under the Board of Trade regulations, a rail weighing not

less than 90 pounds per yard must be used, so that an approximate estimate of the drop in the return circuit can be formed at the outset. The balance of the drop will then give that allowed for the feeders, and they should be designed to conform to this as nearly as possible. There is a great difference between the maximum and average loads in the stations, and the smaller the

TABLE VII
RESISTANCE OF HARD-DRAWN
COPPER TROLLEY WIRE

Gauge	Resistance at 15.5° C. Ohm	
	Per 1,000 Yards	Per Mile
0000000 S.W.G. .	·1246	·2193
000000 S.W.G. .	·1446	·2546
0000 B. & S. . .	·1473	·2596
00000 S.W.G. .	·1669	·2937
000 B. & S. . .	·1816	·3196
0000 S.W.G. . .	·1946	·3426
000 S.W.G. . .	·2251	·3961
00 B. & S. . .	·2292	·4033
00 S.W.G. . .	·2572	·4527
0 B. & S. . .	·2945	·5180
0 S.W.G. . .	·2967	·5222

station, the greater is the difference liable to be. For this reason, the average drop and maximum drop may be widely different. For instance, where the road operates only two or three cars, the load fluctuates between zero and the maximum several times in a minute. Before the size can be assigned to the feeders, the average load that each feeder has to look after must be approximately known or ascertained. In doing this, it is very convenient to divide the line into

sections, assign to each section the load that probably will be on it, and proportion the feeders accordingly.

73. In order to calculate the voltage drop and feeder sizes, it is necessary to obtain a rough plan of the district to be served and the line of route, and to mark on it the position of all cars in use on the days of maximum traffic. The amperage at any point can then be calculated. In cases of a level road and single-truck cars, an average of from 17 to 20 amperes may be taken, and in the case of large double-truck cars, from 24 to 30 amperes.

On lines with abnormal gradients and curves, special allowance must be made. The average distance between the cars running on the system can be easily found, if the average speed and the frequency of the service are known. For example, if there is a 5-minute service, and the average speed of the cars is 6 miles per hour, it takes 10 minutes for a car to run 1 mile. As there is a 5-minute service, each car must have run $\frac{1}{2}$ mile from a given point before the succeeding car passes the same point; the cars are thus spaced $\frac{1}{2}$ mile apart. Taking the same number of cars on the return journey, and assuming that they are spaced midway between the others, there is a car every $\frac{1}{4}$ mile. The same method of calculation can be applied to any other speed or service. It does not make any difference to the spacing of cars whether it is a single or double line, provided that there are enough turn-outs.

74. The general problem may be stated as follows: Given the

size of rails and trolley wire, and the current required at various points, find where positive feeders will be required for the trolley wire and negative feeders for the rails, the size of these feeders, and how the feeder system should be arranged. It must not be forgotten that the maximum drop on the rail return is not to be over 7 volts, and it is better to keep well inside this limit.

75. Resistance of Trolley Wire.—For the purpose of calculating the voltage drop in the trolley wire, it is necessary to know its resistance. This is given for various gauges of hard-drawn

TABLE VIII
RESISTANCE OF SILICIUM-BRONZE
TROLLEY WIRE

Gauge	Resistance at 15.5° C. Ohm	
	Per 1,000 Yards	Per Mile
0000000 S.W.G. .	·1744	·3071
000000 S.W.G. .	·2031	·3574
00000 S.W.G. .	·2342	·4123
000 B. & S. . .	·2601	·4577
0000 S.W.G. . .	·2733	·4811
000 S.W.G. . .	·3159	·5561
00 B. & S. . .	·3289	·5777
00 S.W.G. . .	·3611	·6356
0 S.W.G. . . .	·4164	·7330

copper, per 1,000 yards and per mile, in Table VII, and similar data for silicium-bronze wire are given in Table VIII.

76. Resistance of Return Circuit.—The resistance of the track rails must be known in order that the rail drop may be calculated. For convenience, the resistances per 1,000 yards and per mile of the British standard sections and their weights are given in Table IX.

77. Resistance of Feeder Cables.—When making feeder calculations, it is convenient to be able to quickly find what section of feeder cable will convey a given current with a given drop of

TABLE IX

RESISTANCE OF STANDARD
TRAMWAY RAILS

British Standard Rail Section Number	Weight Per Yard Pounds	Resistance Ohm	
		Per 1,000 Yards	Per Mile
I	90	·0278	·0489
I c	96	·0260	·0458
2	95	·0263	·0463
2 c	101	·0248	·0436
3	100	·0250	·0440
3 c	106	·0236	·0415
4	105	·0238	·0419
4 c	111	·0225	·0396
5	110	·0227	·0400
5 c	116	·0216	·0379

volts per mile. This information is best obtained from curves like those in Fig. 49, which are for cables having sectional areas of copper ranging from .1 to 1 square inch. The dotted line *ab* shows the limit above which the cable should not be worked on account of heating. For example, suppose it is desired to transmit 400 amperes over 1 mile with a drop of 35 volts. The vertical line from 400 amperes on the horizontal scale will be

intersected by a line from 35 volts on the vertical scale on the line marked .50. The section of cable required is therefore .5 square inch, and as the point of intersection is below the dotted line *ab*, the cable will safely carry 400 amperes. Had the point of intersection been above the dotted line *ab*, a larger cable with a smaller drop of volts per mile would have had to be used.

78. Simple Voltage-Drop Calculations.—In order to show how the voltage drop is calculated, take first the case of a single track fed from one end only, with two cars taking 20 amperes each at a distance of 3 miles from the power house. The rails used weigh 90 pounds per yard, and there are two No. 000 S.W.G. hard-drawn copper trolley wires in parallel. The resistance per

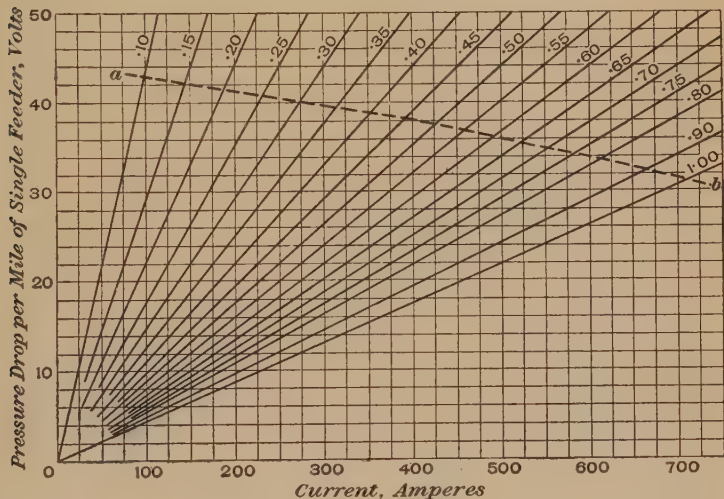


FIG. 49

mile of No. 000 S.W.G. copper trolley wire, from Table VII., is equal to $\cdot 3961$ ohm. The resistance of 3 miles of single wire is therefore $\cdot 3961 \times 3$ ohms, and of the two wires in parallel is

$$\frac{\cdot 3961 \times 3}{2} = \cdot 59415 \text{ ohm. The current taken by the two cars}$$

is $2 \times 20 = 40$ amperes, and the voltage drop in the trolley wires, given by the product of their resistance and the current, is $\cdot 59415 \times 40 = 23\cdot 766$ volts. The resistance per mile of single 90-pound rail, from Table IX, is equal to $\cdot 0489$ ohm, and the resistance of 3 miles of track consisting of two rails in parallel is

$$\frac{\cdot 0489 \times 3}{2} = \cdot 07335 \text{ ohm. The rail drop is therefore } \cdot 07335$$

$\times 40 = 2\cdot 934$ volts. In this simple case the trolley wires are sufficient without feeder cables to carry the required current

without any undue drop. The drop in the rails is also within the 7-volt limit set by the Board of Trade.

79. If two cars are added to the line at the end of each mile, the first two taking 25 amperes each, and the second two 20 amperes each, the route will be as shown in Fig. 50, where a is the power station and b c the route, divided into mile lengths at d and e . The cars are shown at f . The voltage drop in the trolley wire between the end of the route and the first two cars,

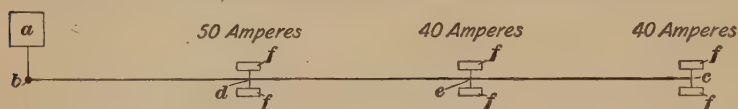


FIG. 50

or between b and d , is the current due to six cars multiplied by the resistance of the wires between b and d ; or $[(4 \times 20) + (2 \times 25)] \times \frac{.3961}{2} = 25.75$ volts, approximately. Between

the first two and second two cars, or between d and e , the voltage drop is the current due to four cars multiplied by the resistance of the wires between d and e ; or $4 \times 20 \times \frac{.3961}{2} = 15.84$ volts,

approximately. Between the second two and third two cars, or between e and c , the voltage drop is the product of the current due to two cars and the resistance of the wires between e and c ; or $2 \times 20 \times \frac{.3961}{2} = 7.92$ volts, approximately. The total

drop, in volts, in the trolley wire is therefore $25.75 + 15.84 + 7.92 = 49.51$ volts, approximately.

The drop, in volts, in the rails between b and d is $130 \times \frac{.0489}{2} = 3.18$ volts, approximately; between d and e the drop is $80 \times \frac{.0489}{2} = 1.96$ volts, approximately; between e and f the drop is $40 \times \frac{.0489}{2} = .98$ volt, approximately; making a total drop in the rails of 6.12 volts, approximately. Since the drop in the trolley wire is 49.51 volts and the drop in the rails

6.12 volts, this is about the limit which would be used without extra feeder cables.

80. If the service just described is doubled, the drop in the line will be about 99 volts, and the drop in the rails about 12 volts. Some alteration must therefore be made in the feeding arrangements to reduce these figures. In such a case, it is advisable to divide the line electrically into two portions, each fed from a separate feeder, so as to localize any trouble arising from defective cars or other faults. This arrangement is shown in Fig. 51, in which *a* is the power station which supplies

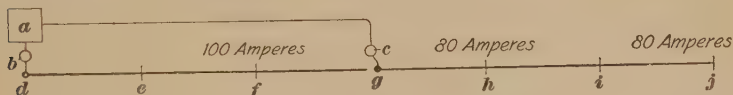


FIG. 51

current to the trolley wires through feeder pillars *b* and *c*. The 3-mile line *dj* is divided at *e*, *f*, *g*, *h*, and *i* into $\frac{1}{2}$ -mile sections by section insulators. The switch pillar at *b* is connected by a short feeder to the power station, and this feeder controls the three $\frac{1}{2}$ -mile sections from *d* to *g*. A feeder taken to feeder pillar *c* controls the three sections from *g* to *j*.

81. The voltage drop in the overhead line *gj* fed by the feeder is the drop in *gh* plus the drop in *hj*; or $(2 \times 80 \times \frac{.3961}{2} \times \frac{1}{2}) + (80 \times \frac{.3961}{2} \times 1) = 15.84 + 15.84 = 31.68$ volts. If the lowest voltage on the trolley wire is to be 495 volts, and the pressure at the power station is 550 volts, the total permissible drop is $550 - 495 = 55$ volts. The drop in the trolley wire is 31.68 volts, so that the drop in feeder *ac* must be $55 - 31.68 = 23.32$ volts. The length of the feeder is $1\frac{1}{2}$ miles, and the drop 23.32 volts; the drop per mile is therefore $\frac{23.32 \times 2}{3} = 15.54$ volts, approximately. The current to be

carried by the feeder is 160 amperes, and from the curve given in Fig. 49, the nearest section of cable is .45 square inch. The drop in the section *dg* is made up of the drop in *df* plus the drop in *fg*. As the drop in *fg* is zero, the drop in *dg* equals

the drop in $d f$; or, $100 \times \frac{.3961}{2} \times 1 = 19.80$ volts, approximately.

In order to reduce the drop on the rails, either return cables must be laid or a return cable laid in conjunction with a negative booster.

82. Effect of Distributed Load.—So far, the feeder problems have been worked out on the assumption that the load was bunched at one end. This is a condition that sometimes arises in practice, but it can hardly be looked on as the ordinary operating condition. In most cases, a number of cars are spaced at fairly regular intervals along the line, each car moving at an approximately uniform rate, with the result that current is taken off at a number of points that are continually shifting. The load

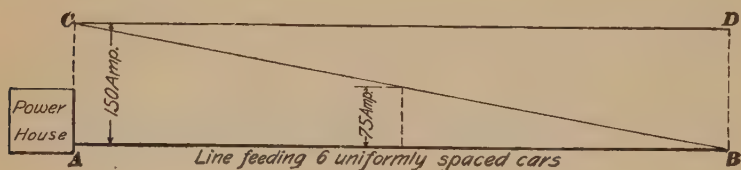


FIG. 52

is nearly uniformly distributed and there is a gradual falling off in current from the station to the end of the line. For example, suppose that AB , Fig. 52, represents a stretch of line that supplies six uniformly spaced cars moving at a uniform speed and taking 25 amperes per car. On account of the uniform movement and even spacing, the current will decrease gradually from 150 amperes at the station to zero at the end B . The falling off in the current may be represented by the line CB . The drop between A and B will therefore be found by multiplying the average current in AB by the resistance. The average current is evidently one-half the station current, or 75 amperes; hence, if the resistance of AB is $\frac{1}{2}$ ohm, the drop between A and B will be 37.5 volts.

83. If the whole load is bunched at B , Fig. 52, the current will be 150 amperes throughout the whole length, as represented

Since there are twelve cars, each requiring 20 amperes, in section *A*, considering the load as being concentrated at the centre, the drop in the trolley wire of this section is $12 \times 20 \times \frac{.3961}{2} \times \frac{3}{4} = 35.65$ volts, approximately. Table IX gives the resistance per mile of a 95-pound rail as .0463 ohm; therefore, the voltage drop in the rails in section *A*, in which the four rails are in parallel, is $240 \times \frac{.0463}{4} \times \frac{3}{4} = 2.08$ volts, approximately.

85. If it is decided to feed this section by means of a short feeder f_a run to the point *G*, the additional drop in the feeder must be allowed for. This cable will be $\frac{1}{2}$ mile in length, and if 14.35-volts drop is allowed in it, a maximum of 50-volts positive drop at the farthest point of the line will be obtained. The drop per mile in the cable is therefore $14.35 \times 2 = 28.7$, and the current to be carried is 240 amperes. From the curve shown in Fig. 49, the nearest larger section of cable is found to be .4 square inch. Section *B*, Fig. 53, is exactly the same as section *A*, so that a second .4-inch cable f_b will be run to *G*, the drop in the trolley wire being 35.65 volts, and the drop in the rails 2.08 volts.

In the present instance there is a drop of about 15 volts in the cable and a drop in the line of about 35 volts, but it would be equally good electrically to allow a larger drop in the cable and a smaller drop in the line, so long as the total drop remains the same. A larger drop in the cable will mean that a smaller cable may be used, but an additional distributing cable would be required from *G*, Fig. 53, to the first section insulator to reduce the drop in the line. The greatest care must be taken to fix as the minimum size a cable which will carry the current safely; in the present instance, a cable less than .25 square inch in area would not be used.

86. In the outlying section *C*, Fig. 53, which extends from *K* to *M*, the voltage drop in the trolley wires is the product of the current and the resistance of one-half the route length of line. As there are four cars per mile, or eight cars, on this section, and

as these take 20 amperes each, the drop is $160 \times \frac{.3961}{2} \times 1 = 31.69$ volts, approximately. The voltage drop in the rails is $160 \times \frac{.0463}{2} \times 1 = 3.7$ volts. The length of feeder f_c required to connect one end K of the section C to the station is 2 miles; therefore, the greatest drop permissible in it is $50 - 31.69 = 18.31$ volts. The drop per mile in the cable is thus $\frac{18.31}{2} = 9.15$ volts, approximately, and the current is 160 amperes. From the curve shown in Fig. 49, the section of cable required is .8 square inch.

This section is, however, much too large, considering the current which it will have to carry, as a much smaller cable will carry 160 amperes safely. It is therefore necessary to consider whether there is a more economical method of dealing with this section. If a .35-square-inch cable is used, the drop in it will be 40 volts, so that the line drop must be only 10 volts instead of 31.69. To reduce the line drop to 10 volts will require along the route a heavy distributing cable, which will have to carry about two-thirds of the current. Its resistance must therefore be one-half that of the trolley wires, or .099 ohm; a cable about .45 square inch is therefore needed. It is thus clear that 2 miles of .35-inch cable and 2 miles of .45-inch cable are required. This means that the weight of copper required is the same as before, because the combined sections of the cables are the same, that is, $.35 + .45 = .8$.

87. Another method which could be adopted is to install a positive booster in conjunction with the .35-inch feeder from the power house P to the end K . This booster would supply the difference between 40 volts and 18.31 volts, or 21.69 volts. As the current passing is 160 amperes, the output of the booster must be $21.69 \times 160 = 3,470$ watts = 3.5 kilowatts, nearly. Any of these methods could be successfully adopted. The most economical method may be found by applying Kelvin's law, making the cost of the watts lost in transmission equal to the interest on the capital cost plus the allowance for depreciation.

88. As regards the return, the drop in the rails from *T* to *G* is 2·08 volts, and the drop from *M* to *G* is $2\cdot08 + 3\cdot7 = 5\cdot78$ volts, both of which values are within the Board of Trade limit. The earth plates are placed at *G*, and the negative feeders connected between the rails at *G* and the power-station bus-bars. The total current returning on these cables is $240 + 240 + 160 = 640$ amperes, so that the minimum size which may be used, as shown in Fig. 49, must have a sectional area of about ·9 square inch. If this section is adopted, the drop, in volts, per mile, from Fig. 49, will be 31·2. As the feeder is $\frac{1}{2}$ mile long, the voltage drop in it will be $\frac{31\cdot2}{2} = 15\cdot6$. The total

drop in section *A*, Fig. 53, will therefore be $35\cdot65 + 2\cdot08 + 14\cdot35 + 15\cdot6 = 67\cdot68$ volts. In section *B*, the drop will also be 67·68 volts. In section *C*, it will be $31\cdot69 + 3\cdot7 + 18\cdot31 + 15\cdot6 = 69\cdot3$ volts. By operating the power-station generators at 570 volts at full load, a minimum pressure of 500 volts at the farthest point of the line may be obtained. At the nearest point to the station, the line voltage will be the station voltage less the drop in the feeders between the station and *G*, or $570 - (14\cdot35 + 15\cdot6) = 540$ volts, approximately. The Board of Trade test wires will be run to the points *T*, *K*, and *M*.

ACCIDENTS DUE TO FALLEN TROLLEY WIRES

METHODS OF DEALING WITH FALLEN WIRES

89. **General Instructions.**—Should a trolley wire or its suspension break, or a telegraph or telephone wire fall and come in contact with a trolley wire, the fallen wires should not be interfered with unless it is necessary to do so to prevent injury or to save life. The current should at once be cut off from the section by means of the switches in the feeder pillars, and notification of the accident sent to the power station. Many feeder pillars are in telephonic communication with the power station, so that help can be summoned when the current is cut off. If a wire, as it lies in the street, is an obstruction to traffic, it may

be pulled on one side by means of a stick, such as a walking stick with a hooked handle, or it may be moved by a person wearing india-rubber gloves. As the wire, especially if thin, may be hot, the rubber gloves should be protected by using a silk scarf, cloth cap, or similar article, in addition.

90. If the fallen wire is in contact with anyone, and it is necessary to remove it at once to save life or prevent injury, the following precautions must be observed :

1. Never touch the trolley wire, nor any person or metallic substance in contact with it, with bare hands or damp gloves.

2. The wire or the person in contact with it may be safely handled by using india-rubber gloves, dry clothing, dry rope, or a dry stick. It is most important that the article used should be dry, as damp material will act as a conductor. A dry india-rubber mat, such as is often used in cabs, carriages, or at shop doors, forms an excellent insulator, and a person standing on such a mat can handle the trolley wire freely, though it is best not to use the bare hands. A dry mackintosh is an excellent material to use when handling the trolley wire.

3. If it is not possible to get the person out of contact with the trolley wire, or to cut off the current at once, the fallen wire may be forced into contact with the tramway rails by the use of a dry wooden pole or a large piece of dry wood. This will result in a short-circuit, accompanied by a very violent flash ; the fallen wire should, however, be held firmly in contact with the rails, and the person in contact with the wire released. If cutting appliances with insulated handles are available, the trolley wire may be cut at a point between the victim and the overhead portion of the wire.

APPARENT DEATH FROM ELECTRIC SHOCK

91. **Application of Artificial Respiration.**—In cases of apparent death from electric shock, restorative measures should be started without a moment's delay when the patient has been removed from contact with the live conductor, and a doctor should be sent for at once. The first step is to apply **artificial respiration**, and this should be persevered in for several hours. When

artificial respiration is applied, the chest is first made to expand, thus enlarging its cavity and causing the air to be sucked in, just as a pair of bellows fills with air when opened. Then the chest is made to contract, so that its capacity for holding air is reduced, and the air is thus forced out. When these movements are performed alternately, there is first inspiration, then expiration, and the two together constitute respiration, or breathing.

92. Method for Three Operators.—To produce artificial respiration, place the patient on his back, with the back just below the shoulders resting on a roll of clothing, so that the pit of the stomach is just above the level of the rest of the body. Next, the teeth must be gently but firmly forced apart, using a piece

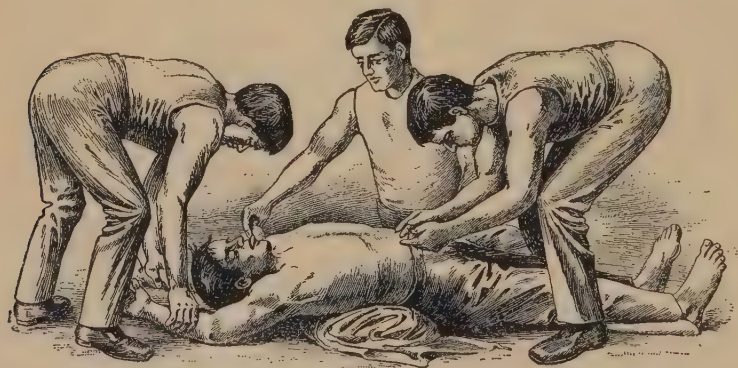


FIG. 54

of wood or the handle of a pocket-knife if necessary, and the tip of the tongue must be drawn forwards and out of the mouth, as otherwise it will fall back into the throat and impede the breathing. This is an important matter, for if it is not done successfully, all that would otherwise be gained by artificial respiration may not be accomplished. An assistant should grasp the tongue with a dry handkerchief, or other cloth, to prevent its slipping from the fingers; or he may cover his fingers with sand for the same purpose, kneeling meanwhile at the side of the patient, as shown in Fig. 54, and holding the tongue out in such a manner as not to let his hand and arm interfere with the movements now to be described.

93. After the position of the tongue has been adjusted, another assistant should kneel or stand behind the patient's head, grasp him by the forearms half-way between the elbows and wrists, and draw the arms up over the patient's head by moving them in a vertical plane rather quickly, but steadily, until the hands touch the ground or floor behind the head, as shown in Fig. 54, holding them there for 2 seconds. This motion draws up the ribs, expanding the chest so that air enters; the arms being held thus for 2 seconds allows sufficient time for the air to completely fill the lungs. Now reverse the first movement, that is, carry the arms back until they are parallel to and near the sides of the chest, as shown in Fig. 55, the assistant who



FIG. 55

is holding the tongue changing hands, if necessary, to let the arms pass. Press the forearms firmly downwards for 1 second. This pressure depresses the ribs, contracts the chest, and forces out the air.

94. While this is being done, let a third assistant take a position astride the patient's hips, with his elbows resting on his own knees and his hands extended ready for action. Just before the patient's hands reach the ground, the man astride the body should grasp the body with his hands, the balls of the thumbs resting on either side of the pit of the stomach, the fingers falling into the grooves between the short ribs. Now, using his knees as a pivot, he should, at the moment the patient's hands touch

the ground, throw, not too suddenly, all his weight forwards on his hands, and at the same time squeeze the waist between them, as if he wished to force something in the chest upwards out of the mouth. He should increase the pressure while he slowly counts one, two, three, four (about 2 seconds), and then suddenly let go with a final push, which will throw him back to his first position. This completes expiration.

95. At the moment the pressure is taken from the waist, the man at the patient's head will again steadily draw the arms upwards to the sides of the patient's head (the assistant holding the tongue again changing hands to let the arms pass, if necessary), holding them there while he slowly counts one, two, three, four (about 2 seconds). These movements should be repeated alternately, regularly, and persistently, and at the rate of sixteen times per minute, until some effort is made by the patient to breathe. This effort may be only a gasp. Wait a moment to see if the patient will breathe again ; if not, again perform artificial respiration, but now endeavour to time the movements by the efforts to breathe, and at the same time resort to hartshorn or smelling-salts, dashing cold water in the face, and slapping and rubbing the surface of the body, until gradually respiration is established. If the patient does not show signs of breathing, do not give up or lose confidence. It is a fallacy to suppose that persons are irrecoverable because life does not soon make its reappearance ; persons have been restored after many hours' work.

96. Immediately after a spontaneous effort to breathe is perceived, stop imitating the movements of breathing, and proceed to induce circulation and warmth. After respiration has been restored, be careful to let the air circulate freely about the patient. On the restoration of breathing, a teaspoonful of warm water should be given ; and then, if the power of swallowing has returned, follow by small quantities of wine, warm brandy and water, or coffee. The patient should be kept in bed, and a disposition to sleep encouraged. If there is pain or difficulty in breathing, apply a hot linseed poultice over the chest. Watch the patient closely for some time, lest the breathing should fail ;

should any signs of failure appear, at once recommence artificial respiration.

97. Method for One Operator.—To produce respiration artificially, if no assistance is at hand and one person must work

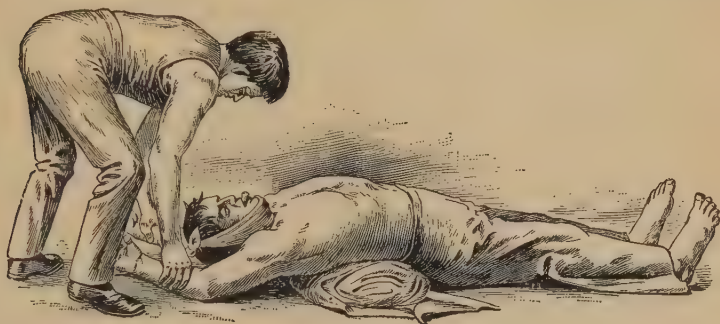


FIG. 56

alone, place the patient on his back with the shoulders slightly raised on a folded article of clothing ; draw forwards the tongue and keep it projecting just beyond the lips by tying it between the teeth, as shown in Figs. 56 and 57, or, better still, with an



FIG. 57

elastic band, if there is one at hand, slipped under the chin. Grasp the arms just below the elbows and steadily draw them upwards in a vertical plane by the sides of the patient's head, allowing the hands to nearly meet, as shown in Fig. 56. Next, swing the arms down to the sides and press firmly downwards

and inwards on the sides and front of the chest over the lower ribs, drawing toward the patient's head, as shown in Fig. 57. Repeat these movements 12 to 15 times every minute.

98. Precautions.—In any operation for restoring respiration, remember the following precautions: Prevent unnecessary crowding of persons round the patient, especially if in a room. Avoid rough usage. Do not allow the patient to remain on his back, unless the tongue is secured. On no account place the patient in a warm bath, unless under medical direction, and even then this expedient should be employed only as a momentary excitant. Always place a wedge of hard rubber or wood between the patient's teeth, as returning animation is usually accompanied by a spasmodic closing of the jaws which is liable to injure, if not to sever, the patient's tongue, since it is being held forward either by the teeth or by another operator, who might not release it quickly enough. When the operator is alone, the tongue should not be held directly by the teeth; it should be placed between the folds of a piece of cloth or paper so arranged as not to impede breathing.

TRAMWAY CARS AND EQUIPMENT

CONSTRUCTION OF CARS

CAR BODIES

SINGLE-DECK CARS

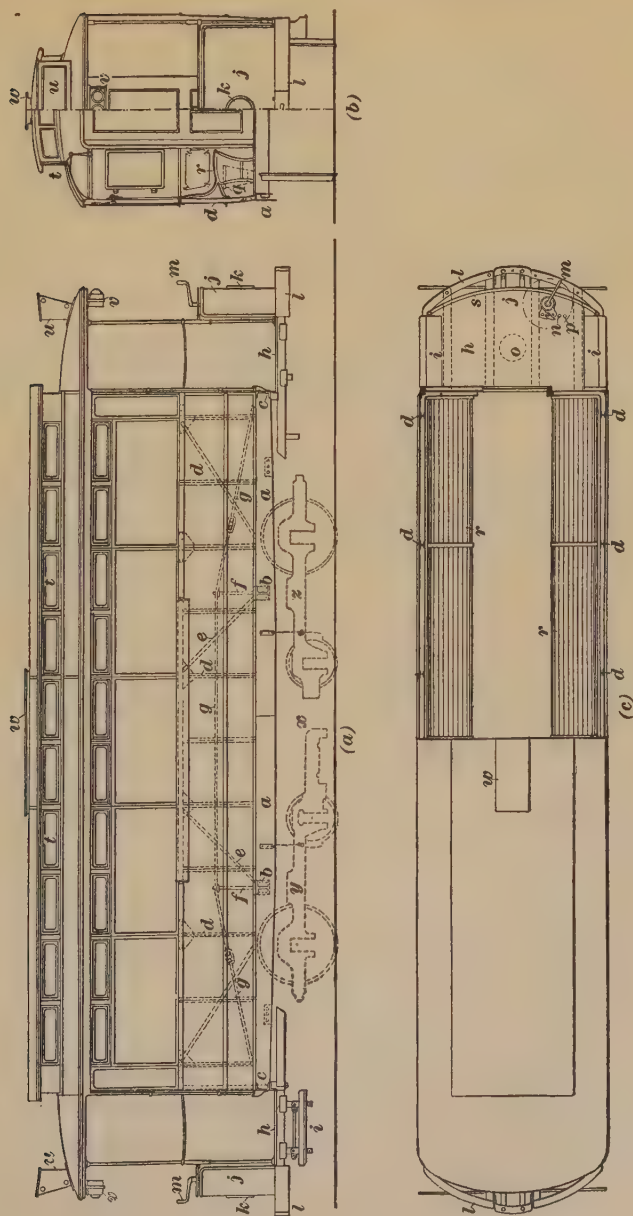
1. **Types of Cars.**—The cars used for conveying passengers on tramways may be **single-deck** or **double-deck cars**, according to whether seating accommodation is required on one floor, immediately accessible from the ground level, or on two floors or decks, the upper one of which is reached by means of stairs. Single-deck cars are not used very much in the British Isles or in France, but otherwise they are the standard nearly all over the world. Where single-deck cars are used exclusively, the heavy traffic of the morning and evening and of holiday times is carried by using *trailer cars*, which are drawn behind the ordinary *motor cars*, as they have no means of independent propulsion. Motor cars are independently driven units, each being complete with motors, controlling devices, and means of collecting current from the trolley wire or working conductor. In the British Isles the Board of Trade regulations forbid the use of trailer cars, so that the cars must be built for the maximum number of passengers that are to be carried at the busiest hours, at the expense of propelling a certain amount of unnecessary weight at the times of lightest traffic. Cars mounted on two trucks are known as **double-truck**,

or **bogie, cars**; those mounted on a single truck and running on four wheels are known as **single-truck cars**. The motors which drive the cars are invariably mounted on the trucks between the car wheels.

2. Arrangement of Single-Deck Cars.—The use of single-deck cars in the British Isles is mainly confined to special purposes. When of the *open type*, that is, without enclosing panels and windows at the sides, they are used for summer excursion traffic at seaside resorts. The *semi-convertible car*, which has side panels, and windows which can be opened or closed as desired, is also used. Passengers can enter or leave the open-type car by stepping on or off at any point on either side, but the semi-convertible car has doors only at the ends. Single-deck cars are also used on certain routes where railway or other bridges are too low to allow the use of double-deck cars, and also in shallow subways immediately below the street level, as in the case of the London County Council subway underneath Aldwych and Kingsway.

3. Single-Deck Steel Car.—The ordinary tramway car for use on the surface usually has a wooden body, or superstructure, built on a steel *underframe*, which is supported on the truck or trucks. The shallow subway cars of the London County Council are built entirely of steel, in order to prevent danger from fire. One of the cars, built by the United Electric Car Company, is shown in Fig. 1 (*a*), (*b*), and (*c*), which gives side and end elevations and plan of the car body, respectively. The underframe consists of longitudinal sole bars *a*, formed of rolled-steel angles, which support cross-joists *b* and terminate in channel bars *c* at the end of the car body. The double-channel pillars *d* form the framework of the car body, which is stiffened by the diagonals *e*. The underframe is stiffened by a truss composed of the vertical struts *f* and tie-rods *g*. The sides of the car are completely closed by panelling and glass, the passengers entering and leaving by doors at the ends.

4. The driver's and conductor's platforms *h* are carried on extensions from the sole bars *a*, and access to the platforms is gained by the steps *i*. The curved dash *j* has a glazed opening *k*



for a head-light, while collision fenders *l* serve to minimize injury to the car in case of accident. On each platform are the brake handle *m*, pedal *n* for sounding the signal gong *o*, and pedal *p* for sanding the rails, the sand being stored in a box *q* under the car seat *r*. The electric controller by which the car is operated is placed on each platform at *s*. The roof of the car is of the clerestory type, with glazed clerestory *t*. Route indicators *u* and signal-lamp indicators *v* show the destination and route of the car. On the top of the clerestory is the trolley board or plate *w*, on which the trolley standard is mounted if current is derived

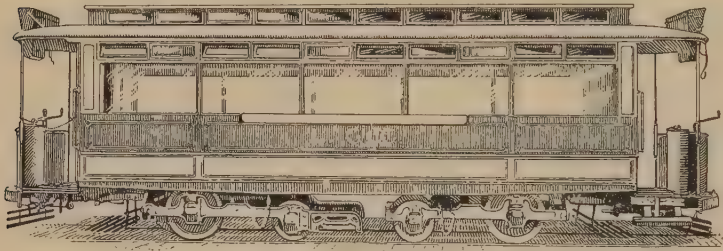


FIG. 2

from an overhead trolley wire. The car shown, however, is worked on the conduit system, and each car carries a plough on the extension *x* of one truck *y*; the other truck *z* is built without any extension. The total length of the car over collision fenders is 33 feet 6 inches, the width over the roof is 6 feet 10 inches, and the height from the rail head to the top of the trolley plate is 11 feet. The total *wheel base*, or distance between centres of outermost wheels, is 14 feet 6 inches. The seats of this car are longitudinal and accommodate 36 passengers. The appearance of the complete car is shown in Fig. 2.

DOUBLE-DECK CARS

5. **Construction of Double-Deck Car.**—A typical British double-deck car, built by the United Electric Car Company for the London United Electric Tramways, is shown in Fig. 3, which consists of a side elevation (*a*) and a plan (*b*). A vertical cross-section is given in Fig. 4, which is drawn to a larger scale than

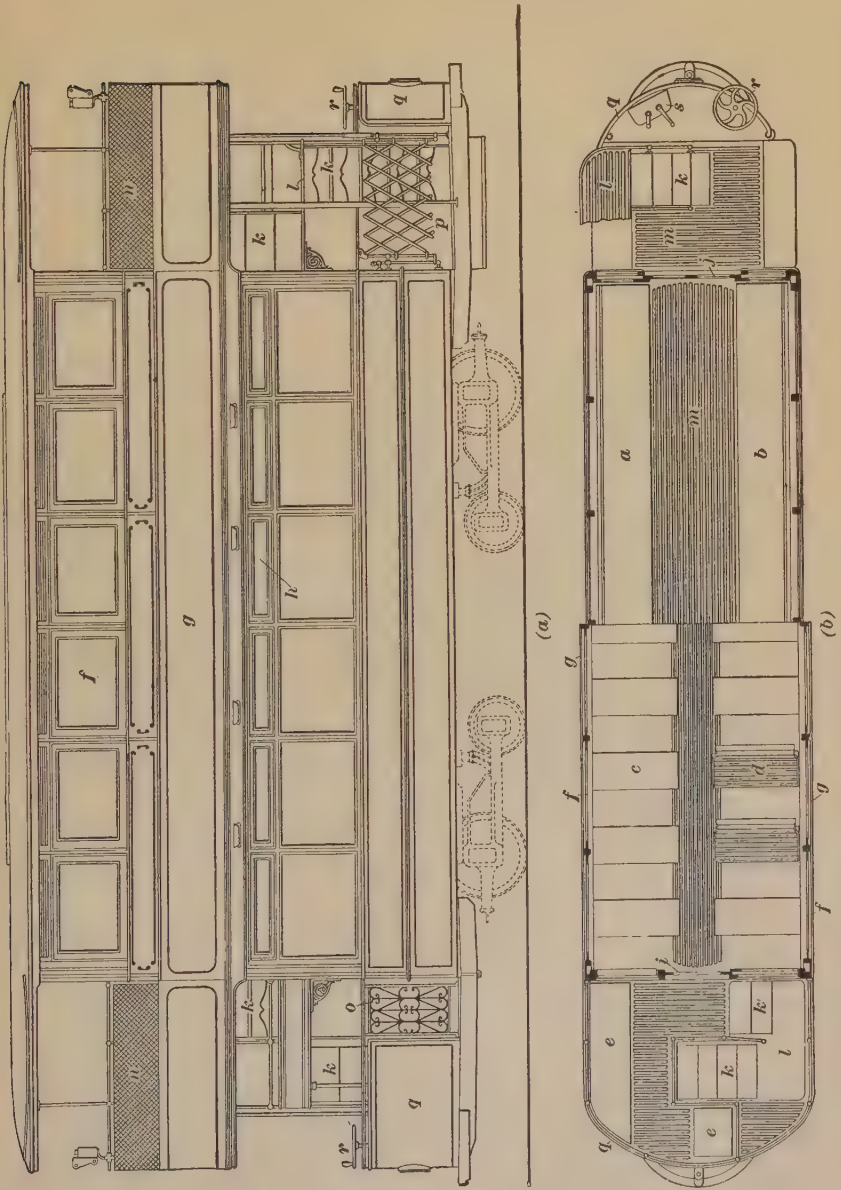


FIG. 3

Fig. 3 in order to show the constructional details ; the lettering is the same for both illustrations. In the type of car illustrated, seating accommodation is provided for 74 passengers, 30 on the lower and 44 on the upper floor, or deck. The seats *a*, *b* on the

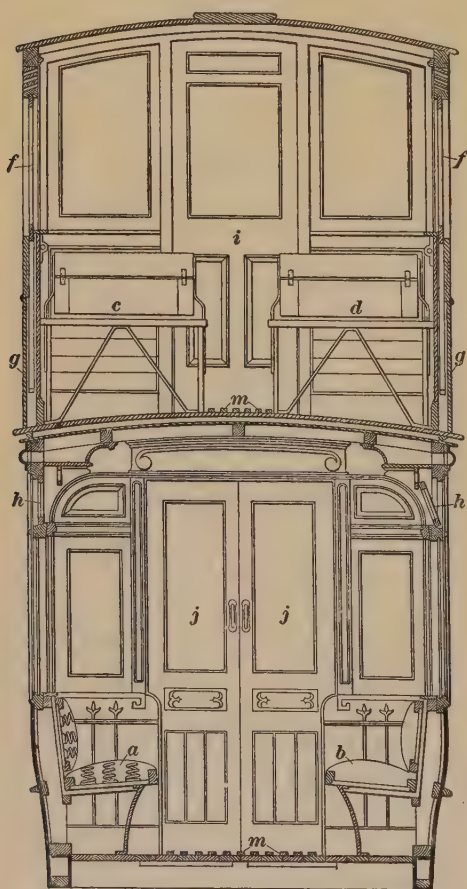


FIG. 4

lower floor are longitudinal, while those *c*, *d* on the upper are cross-seats with swing backs, so that passengers can face either the front or rear ; in addition, four passengers can be accommodated at each end on the outside fixed seats *e*. On the older types of double-deck cars, the top seats were open and no protection from the weather was afforded to the passengers travelling on the outside of the car. The modern tendency is to build a roof over the top seats, and, by carrying the sides up to the roof, to enclose the top deck as well as the lower deck by means of panelling and windows. The upper windows *f* are in this case arranged to open,

by lowering them into a space provided behind the top-deck panelling *g*. The small windows *h* of the lower deck can be opened for ventilation, but the main windows are fixed. Sometimes, however, all the side windows of a car are arranged

so that they can be thrown open in hot weather. Single sliding doors *i* are provided at the ends of the car on the upper deck, and double sliding doors *j* below. Stairways *k* are built to give access to the upper deck at both ends of the car. They are built as left- and right-handed spirals and, as in the present instance, in two straight portions, with a small intermediate platform *l* between them. The car floors and platforms are protected with wearing strips, or slats, *m*; by renewing the slats from time to time, the solid floor is kept sound. The upper platforms are

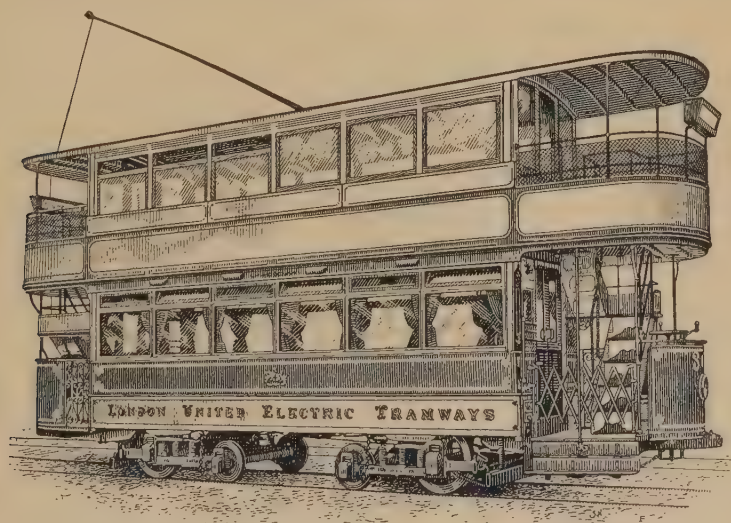


FIG. 5

surrounded by metal screens *n*, and each lower platform can be closed by a swinging gate *o* and a collapsible gate *p*. When driving the car, the driver, or motorman, stands between the stairway and the dash *q*, where he has room to operate the brake hand wheel *r* and controller *s*. The total length of the car over the collision fenders is 34 feet 7½ inches, the maximum width 7 feet 2 inches, and the height 15 feet 10 inches. The general appearance of a double-deck car of the type illustrated in Figs. 3 and 4 is shown in Fig. 5, from which the general arrangement of the car can easily be understood.

TRUCKS

TYPES OF TRUCKS

6. Properties of Trucks.—The functions of a car **truck** are to form a spring support for the car body and a frame for the driving motors and wheels. The motors must be at least partly spring-borne, but the motor-bearing springs must be distinct from the car springs. A truck must be easy-riding and as simple as possible; also, the wearing parts must be easily replaced and few in number. Either one or two trucks may be used on a car, but each truck must be self-contained, the wheels and axles, motors, driving gear, and brakes all being mounted in one independent framework. One *single truck* is used on a single-truck car, and two *double trucks* on a double-truck car. As each truck has four wheels, a single-truck car has four wheels only, while the double-truck car has eight wheels altogether. The choice between single and double trucks depends on the length of car to be supported. The total wheel base must be long enough to support the car body without excessive oscillation, but the rigid wheel base must not be so long that the wheels will bind in the rail grooves at curves. Single trucks, with a wheel base usually of 6 feet, are used for car bodies up to about 28 feet in length, and double trucks, with a wheel base of 4 feet or 4 feet 6 inches each, for all longer cars.

7. Standard Four-Wheeled Single Truck.—The construction of a **four-wheeled single truck**, made by Hurst, Nelson, and Company, is shown in Fig. 6 (*a*), (*b*), and (*c*), which are side elevation, plan, and end elevation of the truck, respectively. The truck is designed for the standard rail gauge of 4 feet 8½ inches, and has a wheel base of 6 feet and wheels of $31\frac{3}{4}$ inches in diameter. The main frame of the truck, consisting of the side bars *a* and end cross-bars *b*, is made of steel, forged solid. The underframe of the car body is bolted to the top plates *c* of the truck, so that the weight is supported and transmitted to the side bars *a* by four helical springs *d* and two elliptic springs *e* on each side of the truck. The helical springs *d* take the principal dead weight of the

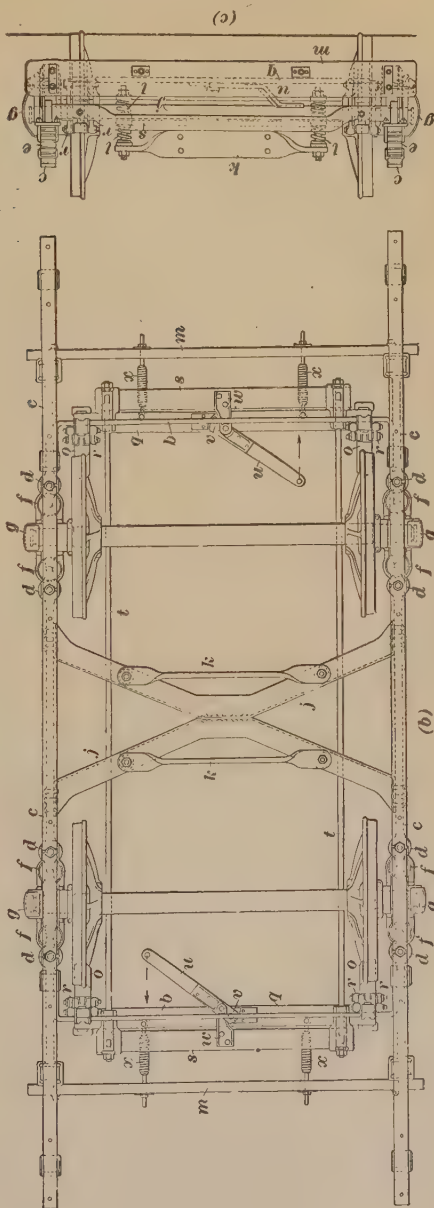
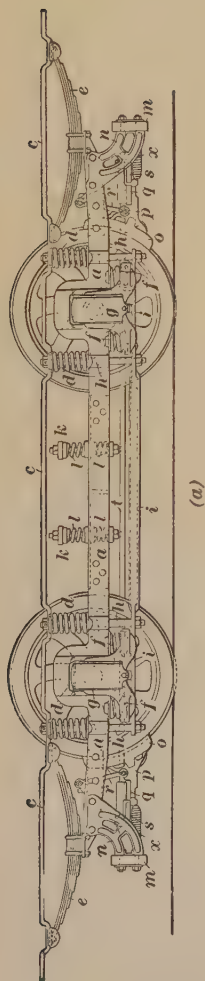


FIG. 6

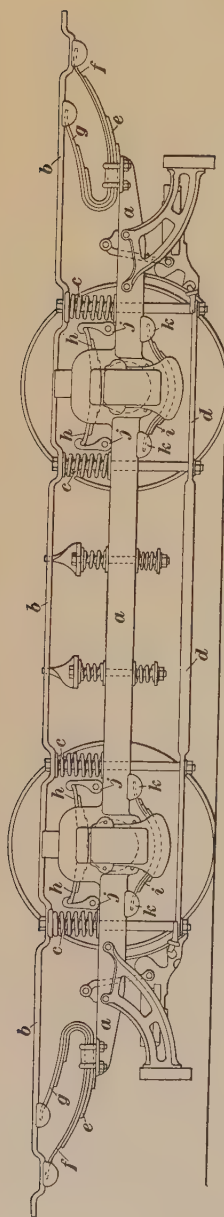
car, while the displacement of the load during the starting and stopping of the car is taken by the elliptic springs, and oscillation of the car is to a large extent prevented. The main side bars *a* of the truck, which carry the whole weight of the car body and truck, rest on the helical axle-box springs *f*, of which there are four on each side of the truck. These springs *f* rest on wings, or brackets, carried out from the sides of the axle boxes *g*, which are themselves hung direct on the car axles, outside the wheels, and are free to slide vertically in guides formed by the vertical limbs of the side bars at these points. The whole side frame of the truck is kept stiff and square by taking the spring posts *h* of the body springs *d* through suitable holes in the side bars and by staying the spring posts together by means of the stay *i*. To prevent vibration and noise, all the spring seats are padded with felt, which is protected by wrought-iron washers.

8. The side bars *a* of the truck frame, Fig. 6, are stiffened laterally by the diagonal brace bars *j*, from which the motor supports *k* are spring-supported; the double motor springs *l* cushion both the up and the down movements of the motor supports *k*. On a single-truck car two driving motors are used, one motor driving on to each axle. The weight of each motor is divided between the axle and motor support from which it hangs. Pilot boards *m* are supported from the side bars at each end of the truck by means of pilot brackets, or braces, *n*; when life guards are used on the car, they are generally attached to the pilot board. The wheel brakes, together with the *brake rigging* by which they are operated, are usually built and supplied by the makers of the trucks. The brake shoes, or blocks, *o* are held in *shoe holders*, or *block carriers*, *p* fixed to the ends of the transverse bars *q*, which are known as the *brake beams*. These brake beams are hung from the truck end bars *b* by means of the brake-block hangers or swinging links *r*. A rectangular frame, formed of the equalizer bars *s* and equalizer rods *t*, rests on the brake beams, and slides on them when the brakes are applied by pulling either brake lever *u* in the direction of the arrows shown in view (*b*). Each brake lever is pivoted to a fixed point *v* on the brake beam, and also to a fulcrum *w* carried by

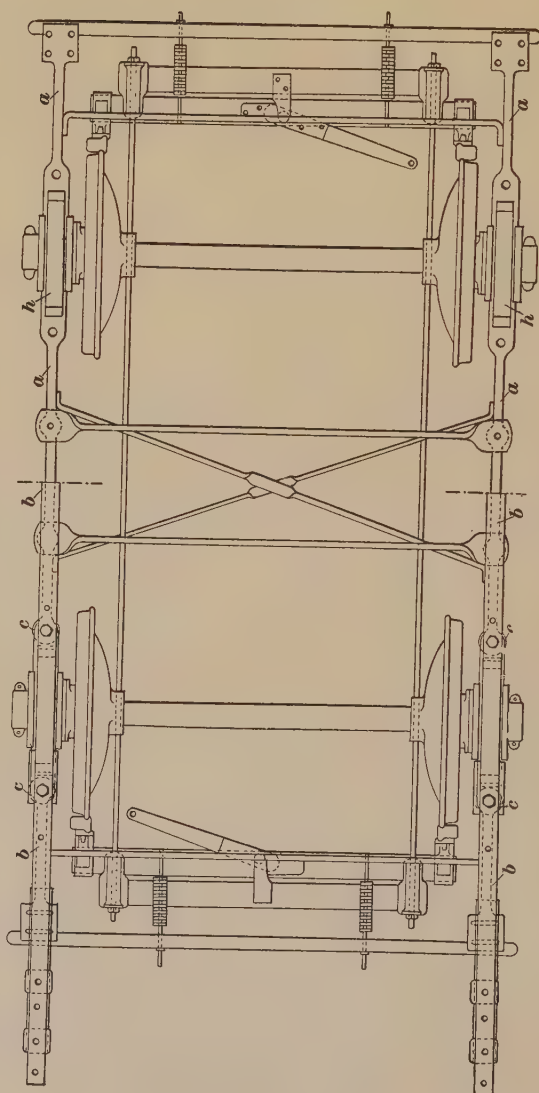
the equalizer bar *s*. The brake blocks are kept away from the wheels, except when the brakes are intentionally applied, by means of the brake-release springs *x*.

9. Compensating Single Truck.—With the ordinary arrangement of springs on the standard four-wheel truck, as shown in Fig. 6, all the springs are in action at all times, whether the truck and car are lightly or heavily loaded. Therefore, if the springs are sufficiently flexible to give easy riding when the load is light, the deflection of the springs will be large when the load is extremely heavy, especially with a double-deck car, and the ability of the springs to take up vibration and to prevent oscillation of the car under such conditions will be greatly diminished. The Preston **compensating truck**, shown in Fig. 7, has been designed to meet heavy-service conditions and to obtain greater freedom from oscillation under all possible conditions of load. This is brought about by the provision of auxiliary springs which only come into action when the truck is heavily loaded. View (*a*) shows a side elevation and view (*b*) a plan of the truck, which has a wheel base of 6 feet and is arranged for a gauge of 4 feet 8½ inches. The general arrangement of the truck frame, including side bar *a*, top plate *b*, body spiral springs *c*, and spring-post stay *d*, is similar to that in Fig. 6. The semielliptic body springs *e*, Fig. 7, are of special shape, with both limbs of each spring extending in the same direction toward the end of the top plate *b* of the truck; the outer end *f* of either spring is always in action, but the inner end *g* only comes into action as the truck is loaded, to prevent longitudinal oscillation of the car. The axle-box springs are elliptic instead of spiral and are duplicated; the top springs *h* carry light loads and are always in action, while the lower springs *i* only come into action on heavy load. The truck side bar *a* hangs from the top axle-box springs *h* by means of the suspension links *j*, while the lower axle-box springs press on spring caps *k*, directly under the side bar of the truck.

10. Double Trucks.—**Double trucks**, sometimes termed also **bogie trucks**, are usually arranged to turn about a certain fixed point, common both to the car and the truck, called the *pivotal*



(a)



(b)

FIG. 7

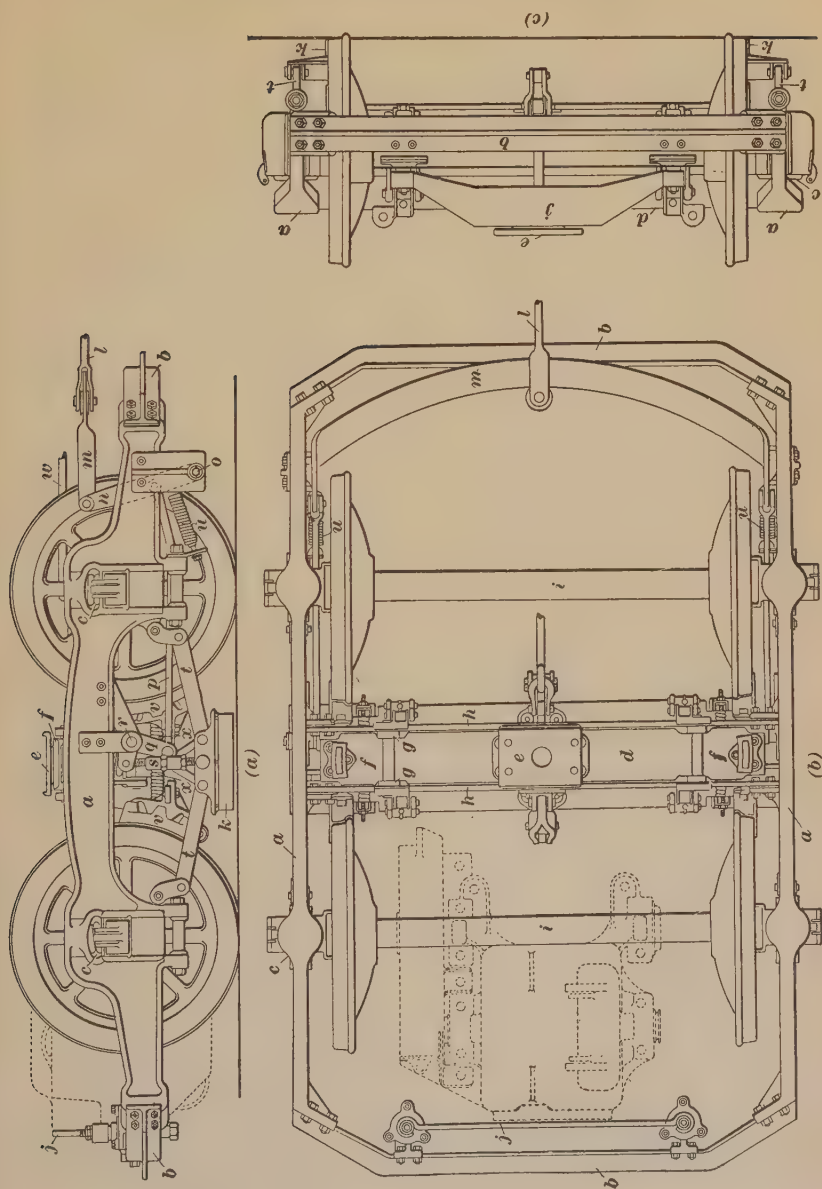


Fig. 8

point; the weight supported by the truck bears on a cross-beam known as the *bolster*. These trucks are therefore sometimes termed *swing-bolster trucks*, since the truck and bolster swing together about the pivotal point. All the wheels of a double truck may be of the same diameter, in which case the truck is known as an *equal-wheel truck*, and may be used with one or two motors. If only one motor is used per truck, the wheels on the driving axle may be of normal size, but the *pony*, or trailing, wheels on the second, or *pony*, axle may be much smaller, these wheels merely serving to guide the truck on the rails.

11. M.G. Equal-Wheel Truck.—A typical equal-wheel centre-bearing swing-bolster truck, known as the M.G. truck, is shown in Fig. 8, where (a) is the side elevation, (b) the plan, and (c) the end elevation. The wheel base is 4 feet 1 inch, the gauge is 4 feet 8½ inches, and the wheels are 31¼ inches in diameter. The frame consists of cast-steel side bars *a*, which are connected by the end cross-bars, or *end sills*, *b*. Helical axle-box springs *c*, mounted on the top of the axle boxes and fitting into cups cast on the under side of the side bars, support the truck frame and the weight of the car body. The bolster *d* supports the car body on the swivel plate *e* and rubbing plates *f*; a centre pin on the car, known as the *king pin*, fits into the centre hole of the plate *e*. The ends of the bolster are spring-supported on helical springs which bear on a spring plank, which in turn is suspended by links *g* from transoms *h* which cross the truck from side bar to side bar. The side swing of the bolster is cushioned by spiral springs bearing against the side frames. The driving motor is hung between one car axle *i* and the spring support *j* carried on the end sill *b*; the outline of a motor is shown dotted in views (a) and (b). The truck is fitted with both track brakes and wheel brakes, which are operated independently of each other. The track-brake shoes *k* are applied to the head of the running rail when a pull is exerted on the brake rod *l*. This pull is transmitted through the arch bar *m*, and thence on each side to the lever *n*, which is pivoted at the fixed point *o*, and then through the tension rod *p* to the crank lever *q*, which is pivoted at *r*. When the lever *q* is turned in a counter-clockwise direction, the push

rod *s* depresses the brake shoe *k*. The brake-shoe holders are hung from the truck side frames by the links *t*, and the shoes are normally held clear of the rail by springs *u* pulling on the levers *n*. The wheel brakes *v* are operated by the brake rod *w* through levers not shown in the drawing. The wheel brakes are kept away from the wheel tires when not in use by means of the springs *x*.

12. Maximum-Traction Trucks.—If only one motor per truck is used, a greater tractive effort can be obtained by arranging for the driving wheels of a double truck to carry a larger proportion of the weight of the car than the trailing wheels. In the **maximum-traction truck**, or **proportional-traction truck**, matters are so arranged that the large driving wheels carry about 70 per cent. of the total weight on the truck, leaving 30 per cent. of the weight only to be carried by the small pony wheels. Using one motor per truck, therefore, on a route with moderate gradients, the maximum-traction truck is better, as regards freedom from skidding of the wheels, than the equal-wheel truck. When heavy gradients are to be climbed, the equal-wheel truck with two motors per truck is evidently the better practice. On level roads, and carrying only moderate loads, the pony wheels of the maximum-traction truck are liable to jump the rails at points or curves, so that, since there is not much liability for the wheels to skid, the equal-wheel truck is preferable even though fitted with only one motor per truck.

13. Brill Maximum-Traction Truck.—A Brill maximum-traction truck, without swing bolster, is shown in Fig. 9. The axles of the driving wheels *a* and pony wheels *b* are kept rigidly parallel, the respective axle boxes *c*, *d* being arranged to slide vertically in guides formed by the side bars *e* of the truck frame. The greater portion of the weight of the car is borne on the side cushions *f*, which are attached to spring posts *g*, and rest on the helical springs *h*. The remainder of the car weight rests on the adjustable spring pillar *i* and is made just sufficient to keep the pony wheels *b* on the track when rounding curves. This truck has no fixed pivotal centre, the point about which it swivels being determined by the four points of contact with the car body,

namely, the two side cushions *f*, the spring pillar *i*, and a king pin attached to the car body and working in a quadrant fixed to the front stay *j* of the truck frame, but not shown in the illustration. Side play of the car body is taken on the rollers *k*, which are recessed in the side cushions *f*, and which bear against rubbing plates on the car underframe. The absence of a central bolster enables the motor to be hung between the axles of the truck. The helical springs *l* cushion both up and down movements of the motor support *m*, while the axle-box springs *n*, *o*, which support the whole weight of the car and truck on the axles, are also of helical form. The brakes *p* are applied to the wheels by a pull rod moving the arch bar *q*, the motion of which

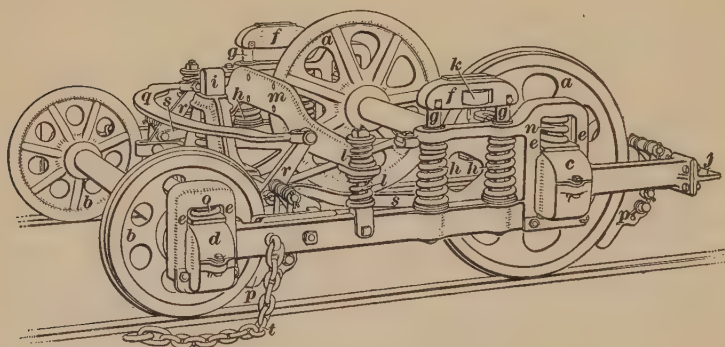
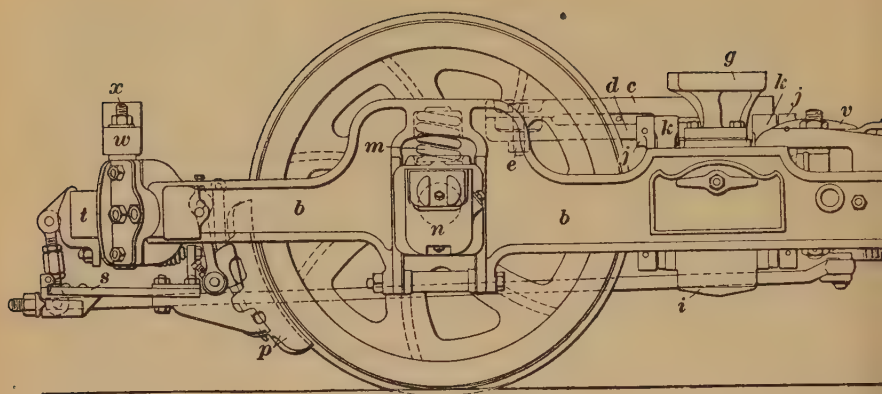


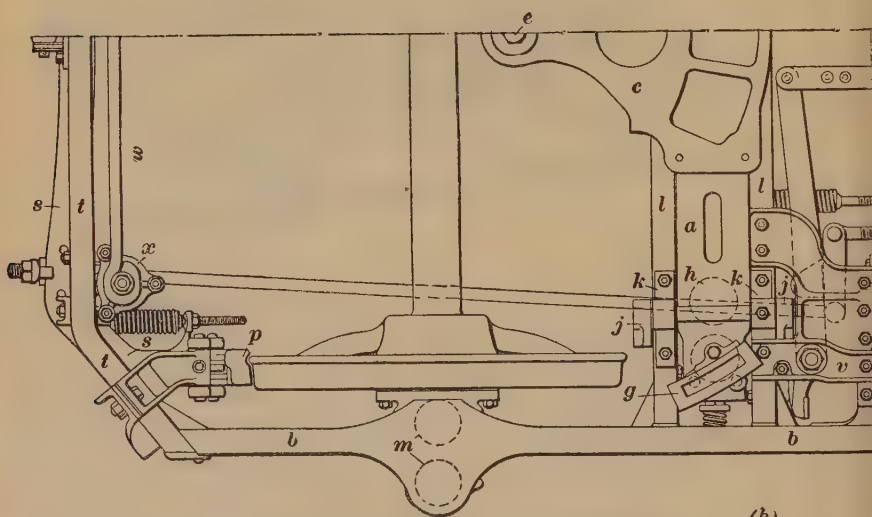
FIG. 9

is transmitted to the blocks through levers *r*, *s*. As the truck swivels in rounding curves, the pony wheels swing under the car; a check-chain *t* is usually attached to the side bar of the truck and to a fixed point on the car underframe to prevent the truck swinging round too far if the pony wheels should jump the rails, or under any other abnormal circumstances.

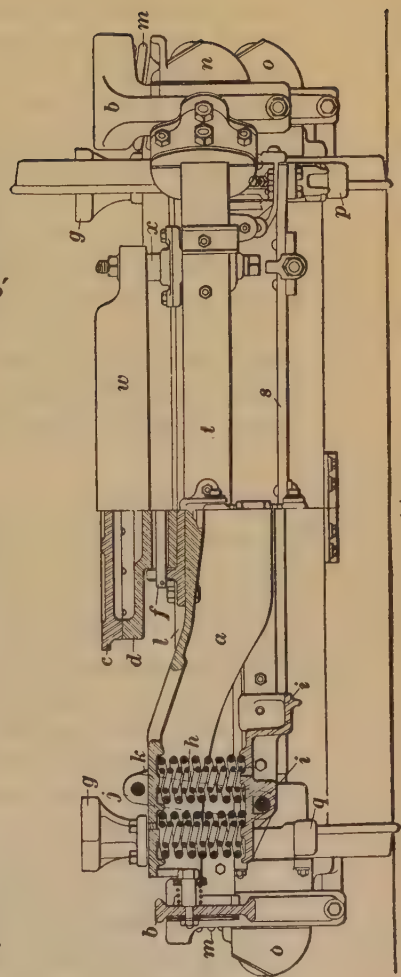
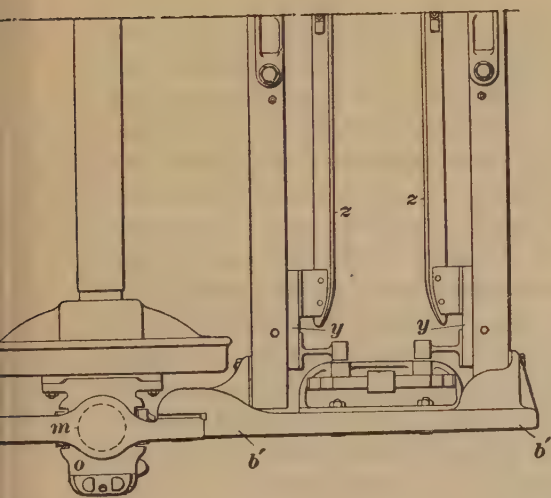
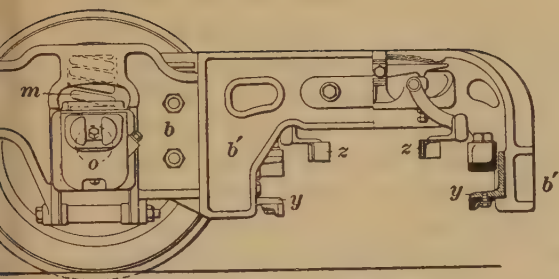
14. London County Council Maximum-Traction Truck. — In Fig. 10 is shown a centre-bearing swing-bolster maximum-traction truck, which is specially fitted with a plough carrier, for use on the conduit system of the London County Council Tramways. The side elevation, plan, and half-sectional elevation are shown, respectively, in views (*a*), (*b*), and (*c*). The bolster *a*



(a)



(b)



is a hollow casting that extends nearly the full width of the truck between the side bars *b*. The car body rests on the top quadrant or swivel plate *c*, which is pivoted to the lower swivel plate *d* at the pivotal point *e*. The lower plate *d*, in turn, is hinged to the bolster at *f*, so that the swivel plates may rock slightly, if necessary, to equalize the distribution of the load on them. An additional rubbing plate or side cushion *g* is bolted to each end of the bolster to balance the car body. The nests of helical springs *h* under each end of the bolster rest on spring planks *i*, which are in turn hung by links *j* to brackets *k* on the transoms *l*. The whole weight of the car is thus transmitted through the springs *h* to the transoms *l*, which are rigidly bolted to the side bars *b* of the truck frame. The side bars are themselves spring-borne by the helical springs *m* on the top of the axle boxes *n*, *o*.

15. The brake blocks *p*, *q* are applied to the respective wheels by exerting a tension on the brake pull rod, which is not shown, but which is pivoted to the central point of the link *r*. The driving-wheel brake blocks *p* are attached to the curved brake beam *s*, and the blocks and beam are hung from the end sill *t* of the truck. The pony-wheel brake blocks *q* are attached to the brake beam *u*, and are hung from one transom by means of the brackets *v*. Since there is not room for the motor to be hung between the axles of the truck, the motor support *w* is carried on the spring pillars *x*, and these are in turn bolted to the end sill *t*. Extensions *b'* of the side bars *b* of the truck form the side frames of the plough carrier. To allow the truck to swivel freely on curves, and in order that the plough may readily be removed from the car, the runners *y*, which support the plough, stretch right across the truck, while the electrical contact bars *z* are 4 feet 5 inches long. The contact bars are curved away toward the ends to provide an entrance for the collector springs with which the plough is fitted. In many cases collector springs are not used, and connection is made to the plough by means of flexible insulated cables.

16. **Truck Bearings.**—A typical axle box and truck bearing of a Brill single truck are shown in Fig. 11. The axle-box casting *a*

has a seat at *b* for the axle-box truck springs, which are helical in form. The top bearing brass *c* carries the weight on the journal *d*, the car axle being shown broken at *e*, where the wheel would be shrunk on. The check-plate *f* is dropped into a

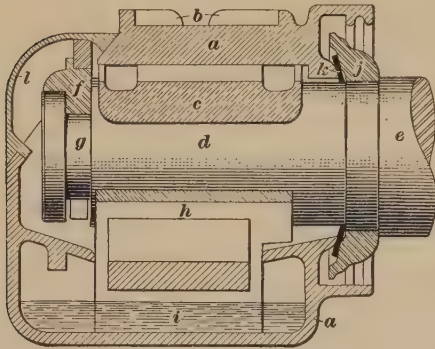


FIG. 11

groove *g* turned at the end of the axle, and limits the end play of the journal in the bearings. The oiler block *h* supports a felt pad, not shown, which conveys oil to the journal from the oil reservoir *i*. The oil-throwing ring *j* prevents oil travelling along the shaft from the axle box, the fibre washer *k*

preventing the oil passing on to the oil thrower when the axle is at rest. The axle-box cover *l* is provided to allow inspection and to permit the removal of the check-plate *f* when it is desired to slide the axle-box off the journal.

METHODS OF SUSPENDING MOTORS ON TRUCKS

17. Position of Motor.—It is usual in tramway work to gear the motors to the car axles by means of a single-reduction gear ; that is, a pinion at one end of the armature shaft drives a spur wheel on the car axle. The weight of the motor is then carried partly on the car axle and partly on the framing of the car truck. It is not possible in tramway work to mount the motor armature direct on the car axles ; in order to suit the low axle speeds, the motors would have to be much larger and much heavier than is necessary when the motors are geared. Moreover, in order to minimize vibration of the car and wear of the track, it is undesirable to carry a greater weight than necessary directly on the wheels without the support of intermediate springs. When the motors are geared, the weight is partly spring-borne, but in the case of the direct drive the whole weight of the motors must usually be carried direct on the axles, in order to maintain the

correct centring of the armature and field. Direct driving is used in the case of some electric-railway locomotives, of which the axle speeds are also suitable as armature speeds of the large sizes of motors used. In these cases, arrangements are sometimes made also to carry the weight of the motors on springs, which would be too expensive to use in the case of tramcars.

18. Nose Suspension.—There are two principal methods of suspending a traction motor from the car truck, known, respectively, as the **nose suspension** and the **cradle suspension**. In either case the motor is hung on the car axle between the car wheels, as shown in Fig. 12, in which the motor occupies a central position between the car wheels: a gear-case, enclosing the spur

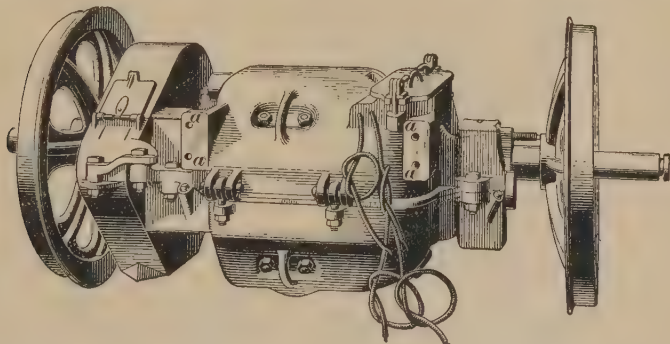


FIG. 12

gear, is shown at the left of the motor. The car axle passes through axle bearings at the rear of, and forming a part of, the motor case. In the nose suspension, the front is supported by a suspension bar bolted to the motor at *a* and resting on springs carried by the side frames of the truck.

In Fig. 13 (*a*) and (*b*) are shown the plan and front elevation of a completed nose suspension. The axle *a* passes through the axle bearings *b*. As this motor does not take up all the space between the wheel hubs, it is prevented from shifting along the axle on the one hand by the spur wheel *g* and on the other by the collar *c*, the position of which can be adjusted by a screw *d*. When the space between the wheel hubs is completely filled, no collar is necessary. When a collar must be used, instead of a split collar *c*,

with a screw adjustment, it is better practice to use a plain solid collar pressed on to the shaft in the same way as the wheels ; it is cheaper than the collar shown and there is no possibility of its working loose. The suspension bar to which the motor is bolted may be straight, as shown at *e'*, or bent, as at *e*, but in either case it is supported by springs *f* carried on the frame of the truck

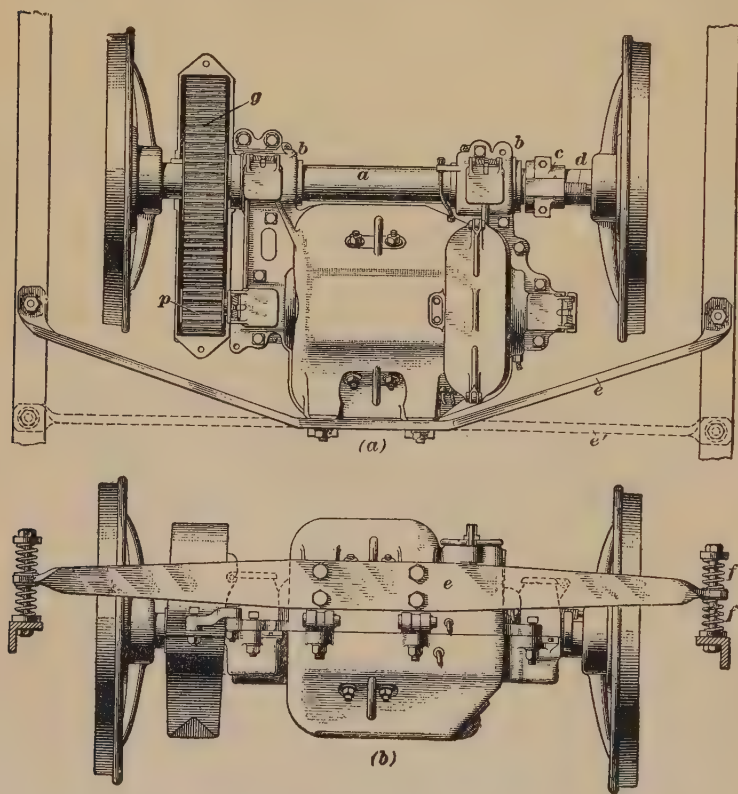


FIG. 13

Whatever kind of suspension is used, the object is to provide a flexible support for at least a part of the weight of the motor, so as to cushion the pounding effect and allow a certain freedom for up-and-down movement as the car passes over irregularities in the track. The stresses on both motors and track are in this way very much reduced.

19. Westinghouse Nose Suspension.—The nose suspension of the Westinghouse 200 tramway motor, shown in Fig. 14, is a very compact arrangement. The motor develops a normal output of 35 horsepower on a 1-hour rating, and is so arranged that it can be placed between the car wheels when spaced for a minimum gauge of 3 feet 6 inches. An end view of the motor and suspension from the gear-box end is shown in view (a); a side elevation, looking at the car axle, in view (b); and the general arrangement in plan in view (c). The axial width of the motor *a*, armature bearings *b*, and gear-box *c* is cut down to a minimum. Instead of bolting the motor frame direct to the suspension bar *d*, a lug *e* on the motor is hung from the suspension bar by a link *f*. In view (a) the dotted lines show the positions of the lower half *g* of the gear-case and the lower half *h* of the motor frame, when swung down in order to inspect the gear-wheels, or the motor armature or field coils, as the case may be. The cases are held closed by means of bolts and are made to fit closely, so as to exclude water and dirt.

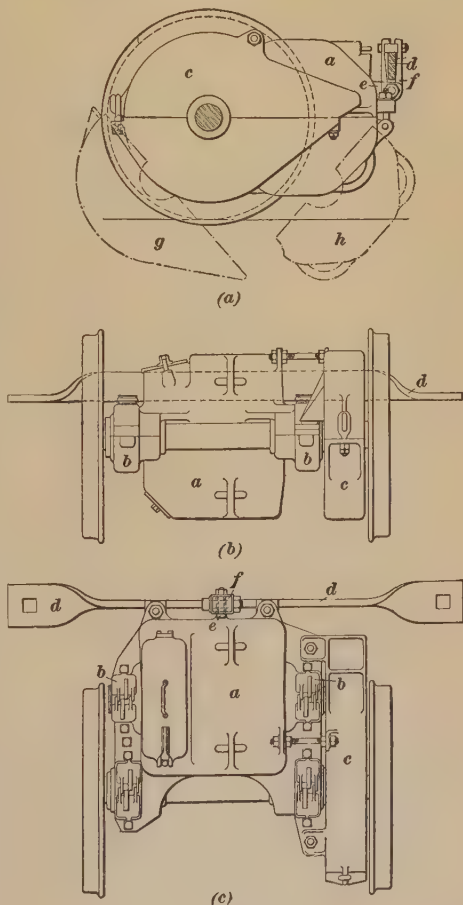


FIG. 14

20. **Double - Geared Drive.**—Since the drive by a single-reduction gear through a single pair of gear-wheels is found to cause unequal wear of the bearings, thus allowing the pinion and spur wheel to lose their alinement and the teeth to wear more

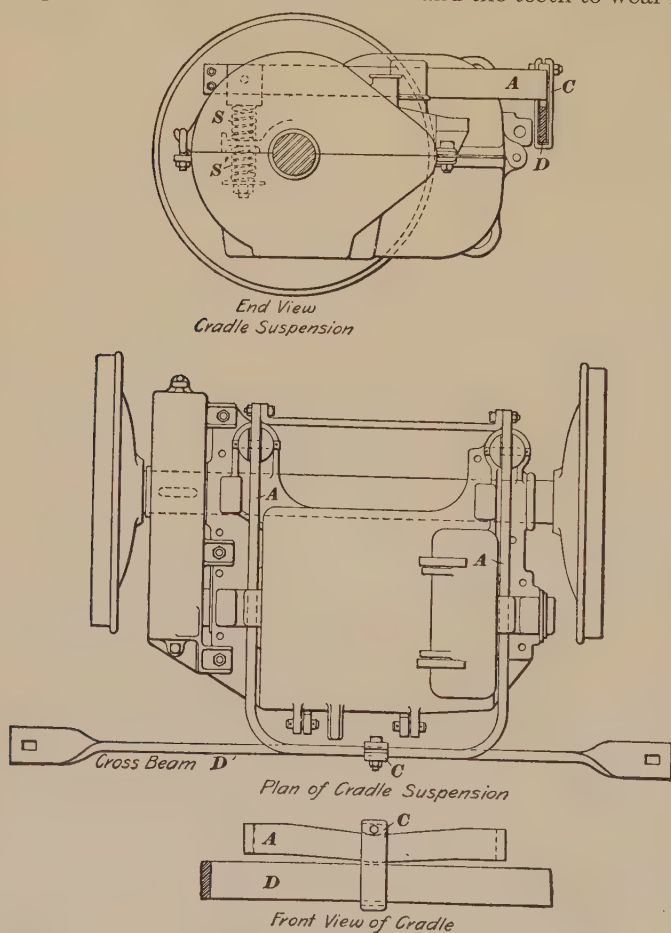


FIG. 15

at one end than the other, it has been suggested that a much better drive can be obtained by using pinions on both ends of the motor shaft, driving on to two spur wheels, one at each end of the axle. Experiments show that, if sufficient room can be

found between the wheels for the extra gear, the results obtained are very satisfactory, both because the running is improved and the expense of upkeep of wheels and bearings is diminished.

21. Cradle or Side-Bar Suspension.—In Fig. 15 is shown a method of suspension sometimes used, in which the motor is supported by a cradle, or frame, *A*. The front of the cradle is supported by a link *C* from the cross-beam *D* that rests on the truck side frames, and in this example the back is supported by means of springs *S*, *S'* that bear against lugs cast on the same arm that carries the axle bearings. The sides of the cradle pass through lugs on the ends of the motor and the whole motor is free to move up and down through a limited range, the movements being cushioned by springs *S*, *S'* and those placed between the ends of the cross-beam and the truck side frame. In some forms of this suspension the side bars are below the centre line of the motor, in which case the ends must be hung from the cross-beam and the axle, respectively, by vertical links. In either case the object is to support the motor at a point as near as possible to its centre of gravity, and thus carry as much as possible of the weight of the motor on the springs.

CAR WHEELS

22. Form and Parts of Wheels.—The various parts of a car wheel are the *rim*, *tread*, *flange*, *boss*, *web*, and *ribs*. The principal wearing portion of the rim *a*, Fig. 16, and that part on which the wheel rolls, is the tread *b*. The flange *c* runs in the rail groove and serves to keep the wheels on the rails. The centre portion *d* of the wheel is known as the boss, while the web *e*, which is usually perforated, supports the wheel rim from the centre, and is itself stiffened with ribs or brackets *f*. The profile of a standard wheel, running on a standard tramway rail, is shown in Fig. 17. The gauge line of the rail is not the same as the gauge line of the wheel, but is slightly displaced, to allow clearance when the wheels are

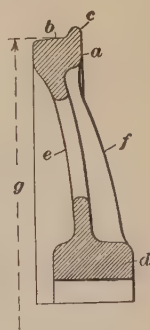


FIG. 16

rolling. For instance, if the track gauge is 4 feet $8\frac{1}{2}$ inches, the wheel gauge will be 4 feet $8\frac{3}{16}$ inches.

23. Size and Material of Wheels.—The diameter of a wheel

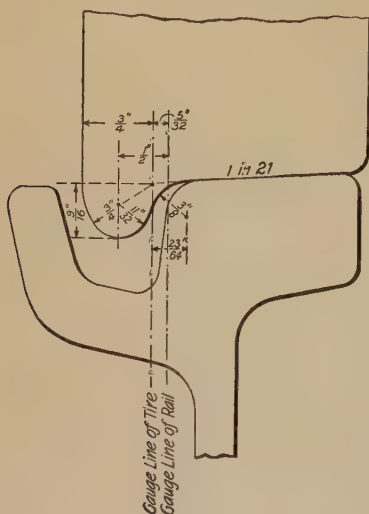


FIG. 17

is always understood to mean the greatest diameter g , Fig. 16, of the tread; for tramway work, this dimension may vary from 20 to 33 inches. The smaller wheels are used as the pony wheels of maximum-traction trucks; the most usual sizes of driving wheels are 30 and $31\frac{3}{4}$ inches in diameter. In Fig. 18 are shown two wheels a mounted on a car axle b , the track gauge being shown by the dimension c . The wheels are bored and the axle turned to a press fit, and the wheels are pressed on hydraulically. The journals d

are of smaller diameter than the remainder of the axle, and run in the truck-axle bearings. The spur wheel of the

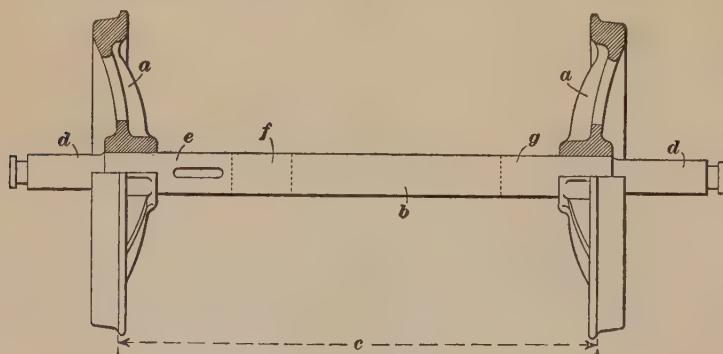


FIG. 18

single-reduction gear is clamped and keyed to the axle at e , and the motor-axle bearings hang on the axle at f, g . The

remainder of the axle, between *f* and *g*, need not be machined to a finish. Car wheels are made either entirely of chilled cast iron or are fitted with steel tires shrunk on centres of annealed cast iron, wrought iron, or pressed steel.

24. Chilled Cast-Iron Wheels.—Chilled cast-iron car wheels possess considerable elasticity and resistance to wear under tramway conditions. They are made from a specially good brand of pig iron, the treads and flanges being *chilled*, or made intensely hard by casting in a mould with metal faces at the tread and flange. The rapid cooling of the casting by the metal faces gives the desired local hardening, while the other faces and interior of the casting remain soft cast iron. The depth of the effective chilling, or hardening, is usually limited to about $\frac{3}{4}$ inch, so that when the wheel wears to this depth it must be scrapped. Within this limit, however, the wearing properties of chilled wheels are excellent. There are certain disadvantages in the use of these wheels, for there is a tendency for the wheel flanges to chip and break, and this tendency is the greater the harder the wheel. Also, since it is impracticable to turn up chilled wheels in the lathe, special means must be provided for grinding the wheels in order to prevent the development of flat places on the tread. These flat places, called *flats*, are made on the wheel treads when too great pressure is applied between the brake blocks and wheels in braking, thus locking the wheels so that they skid, or slide, along the rails instead of rolling. They are usually caused by careless driving, and much may be done to minimize trouble from this cause by the care of the driver in gradually applying the brakes. Since a braked wheel always tends to stop at the point where a flat has already commenced to form, the wheel should be ground true, by means of an emery grinder, before a bad flat is developed.

25. Steel-Tired Wheels.—Steel-tired wheels are much more expensive in first cost than cast wheels, but in some cases their use is more economical in the long run. They are not liable to breakage, and not nearly so likely to develop flats, and when flats do occur they can be removed in the lathe. Steel tires also have a higher coefficient of friction than cast wheels, and

therefore the adhesion of the wheels on the rails is increased, and the brakes are more effective. The tires are usually heated and then shrunk on the centres, so that when a tire is worn out it can be removed and a new one can be shrunk on.

In Fig. 19 (a) and (b) are shown two Griffin steel-tired wheels, the centres being of specially toughened and annealed cast iron.

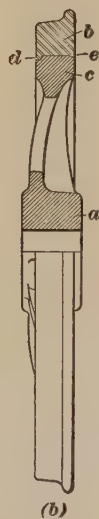


FIG. 19

View (a) shows a standard wheel for a gauge of 4 feet $8\frac{1}{2}$ inches; this wheel is *dished*, that is, the centre line of the boss *a* is set back from the centre line of the rim, in order to give the wheel greater elasticity. The wheel in view (b) is of the *reversed-dish* type, the boss *a* being brought forwards in order to allow the maximum amount of room between the wheels; the reverse-dish wheel is designed specially for use on narrow gauges.

26. Construction of Tired Wheels.

Annealed cast iron is, in general, superior to wrought iron for wheel centres. Since the permissible working stress under compression is greater

for cast iron than for wrought iron, it is possible to allow greater shrinkage in putting on the steel tires than would be advisable with wrought-iron centres. Thus, the use of setscrews to prevent the tire coming off, the holes for which weaken both the tire and the centre, is obviated. In Fig. 19 (a) and (b) the joint between the tires *b* and wheel centres *c* is specially designed for the maximum security. A lip *d* turned on the tire fits in a corresponding recess in the wheel centre. The other side of the centre is turned off to a round corner *e*; after the tire is shrunk on, a projecting rim left

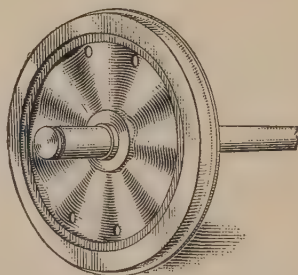


FIG. 20

on the tire is pressed down over the round corner, thus assisting to prevent any movement of the tire.

27. In Fig. 20 is shown one of the truck wheels on its axle, made by the Glasgow Railway Engineering Company, the centres being made in one piece in a hydraulic forging press, with steel tires shrunk on. The life of car wheels is measured by the mileage run before the wheels have to be replaced or re-tired. Chilled wheels have an average life under ordinary circumstances of 30,000 miles, while steel-tired wheels may run a distance of 50,000 or even 100,000 miles before requiring renewal.

LIFE GUARDS

28. **Hudson & Bowring Life Guard.**—The regulations of the Board of Trade provide that every tramcar shall be fitted with an approved pattern of life guard, designed to pick up without serious injury any person falling in front of a moving car. The arrangement of the Hudson & Bowring life guard is shown in Fig. 21; this is known as the *trigger* type. It does not depend

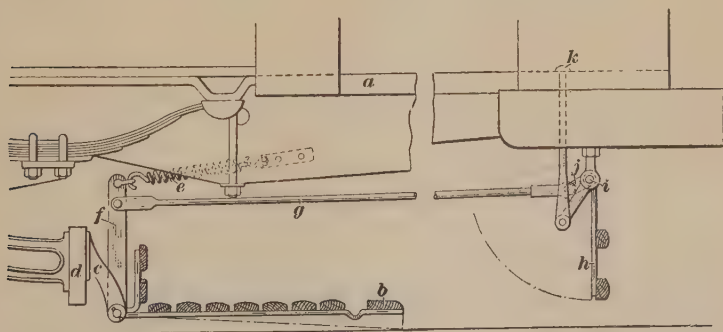


FIG. 21

for its operation on any action of the driver, but is entirely automatic. The life guard is fixed under the platform *a* of the car, and has a falling tray *b* carried normally a few inches above the rail level and pivoted to a bracket *c* fixed to the pilot board *d* of the car truck. The helical spring *e* is fixed at one end to the car-body underframe and pulls on the lever *f*, which is fixed

rigidly to the life-guard tray *b* ; the spring thus tends to lower the falling tray and to hold its front end down to the surface of the road. Any movement of the lever *f* is prevented, however, before the life guard is required to act by the push rod *g*. If the car approaches a person lying on the track, the swinging gate *h*, which is pivoted at a fixed point *i*, is pushed back, and the crank-lever *j* is rotated on the pivot *i* until it is above the dead centre on the horizontal line, thus allowing the spring *e* to force the rod *g* forwards and to lower the tray *b*. The tray is reset by the driver depressing the platform pedal *k* ; this rotates the lever *j* in a counter-clockwise direction, and rod *g* is put into compression, thus raising the tray *b*.

EQUIPMENT OF CARS

COLLECTORS

TROLLEY HEADS

29. The usual method by which current is collected by a moving car is by means of a wheel, called the **trolley wheel**, carried on the end of a **trolley arm** or **trolley boom**, so that it runs against the overhead trolley wire. The casting in which the wheel runs is known as the **trolley head** ; it is either fixed rigidly to the trolley boom, for centre running, or is arranged to swivel on a vertical axis at the end of the trolley arm, for side and centre running, or side running only, according to the type of overhead construction with which it is used. Since the height of the trolley wire is usually not less than 20 feet above the ground, and may be more, the trolley arm is usually from 13 to 18 feet long. The necessary stiffness is obtained by making it in the form of a steel tube that tapers from 2 inches in diameter at the butt to 1 inch at the top.

30. **Construction of Fixed Trolley Head.**—The fixed trolley head is the earlier type and is still used with success on some

centre-running tramway systems in the British Isles, notably at Glasgow. In America the fixed head and the centre-running trolley are used practically to the exclusion of the swivelling head and side-running trolley. This head, as used in Glasgow, is shown in Fig. 22, in which the trolley head *a*, which is a gun-metal casting, carries the trolley wheel *b*, and is itself fixed to the trolley arm *c*. The trolley arm is insulated from the head and wheel by means of the insulating sleeve *d*, which is clamped on a contracted portion of the head by screwing the special nut *e* over the tapered and split sleeve *f*. If current were allowed to pass directly from the gunmetal wheel *b* to the steel spindle *g*, the grease used for lubrication would be dried, and the heat developed and the wear caused would be excessive. In this instance, therefore, springs *h* are provided, which are attached to the trolley head and collect current from the boss of the trolley

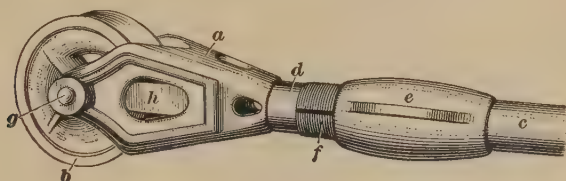


FIG. 22

wheel. It should be noted that the trolley head, as a whole, has no projections at any point which can catch in, and thus damage, the overhead construction in case of the trolley wheel leaving the wire. The material of the head-casting is sometimes malleable iron instead of gunmetal.

31. Swivelling Trolley Head.—A Birkby trolley head, which is a good example of the class of **swivelling trolley heads**, is shown in Fig. 23 (*a*) and (*b*). The brass head-casting *a* is fixed to the trolley arm *b*, and the brass or gunmetal trolley wheel *c* runs on a steel spindle *d* supported in the swivelling part *e*, called the *globe*. The lower portion of the globe is in the form of a spindle, which revolves in a socket in the head-casting, so that the trolley wheel can take up any desired position in the head in order to aline itself with the overhead trolley wire, and is prevented from jumping out by a pin *f* which engages in a groove

in the globe spindle. The shape of the head-casting and globe is designed so as to guard as much as possible against the head catching in the trolley or span wires if the wheel leaves the trolley wire.

32. Sliding Contact Sleeve.—In order to prevent breakage of the trolley or span wire, or damage to the trolley boom or the standard by which it is attached to the car, in the event of entanglement of the head with the trolley-wire construction, the Board of Trade regulations require means to be provided whereby the trolley head can be disengaged from the trolley arm when a pull is exerted on it under these conditions. This

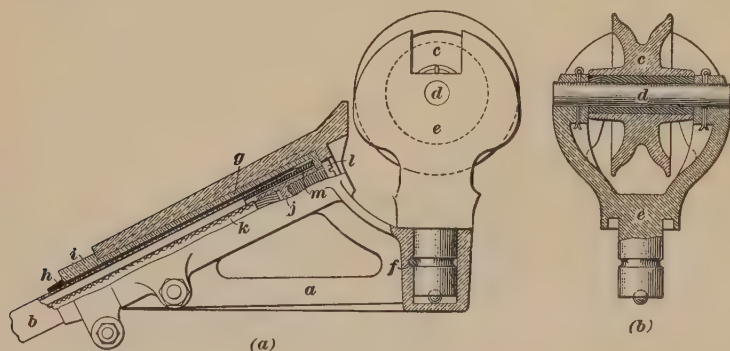


FIG. 23

is provided for in this case by the use of a split sliding contact sleeve *g*, Fig. 23 (*a*). The sleeve is clamped to the trolley boom *b* with a rubber insulating sleeve *h* interposed to insulate the boom, and then the head is slipped over sleeve *g* and clamped up lightly only. A projection *i* on the contact sleeve fits into a slot in the head-casting and prevents the latter turning, but the head is free to pull off in case of accident. The trolley cable connection is made inside the contact sleeve *g* by means of the cable terminal *j*, into which the bared end of the insulated cable *k* is sweated. The terminal is secured by the screw *l*, and is insulated from the steel arm *b* by means of an insulating fibre sleeve *m*. There are usually no collecting springs provided in swivelling trolley heads, for the trolley wheel is bushed with graphite, which is not only a good lubricant, but also a good electrical

conductor. The current passes directly from the trolley wheel to the spindle, and thence through the globe and head-casting to the trolley cable.

33. Self-Righting Trolley Head.—A modification of the swivelling head, used for centre-running systems, is the **self-righting trolley head**, shown in Fig. 24. The globe *a* carrying the wheel *b* is mounted in a socket in the head-casting *c*, and is free to swivel through a limited angle to follow any slight deviation or irregularities in the line of the trolley wire. The motion of the globe is constrained, however, by a spring *d* anchored at *e* to the head-casting, and pulling on a steel pin *f* passing through

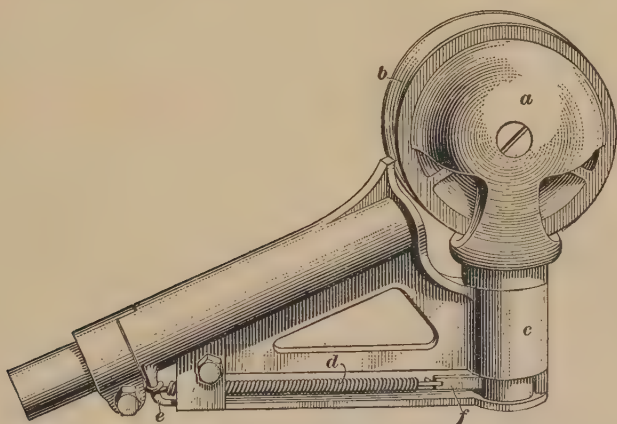


FIG. 24

the lower end of the globe spindle. The tendency of the spring is therefore to keep the axis of the trolley wheel always at right angles to the trolley arm, while the limited amount of flexibility allowed prevents undue strain of the overhead work and the trolley arm, and decreases the amount of wear of the trolley wheel.

TROLLEY WHEELS

34. Choice of Trolley Wheels.—Since the trolley wheel runs directly on the overhead trolley wire, great care must be exercised in choosing the most suitable wheel to use in any

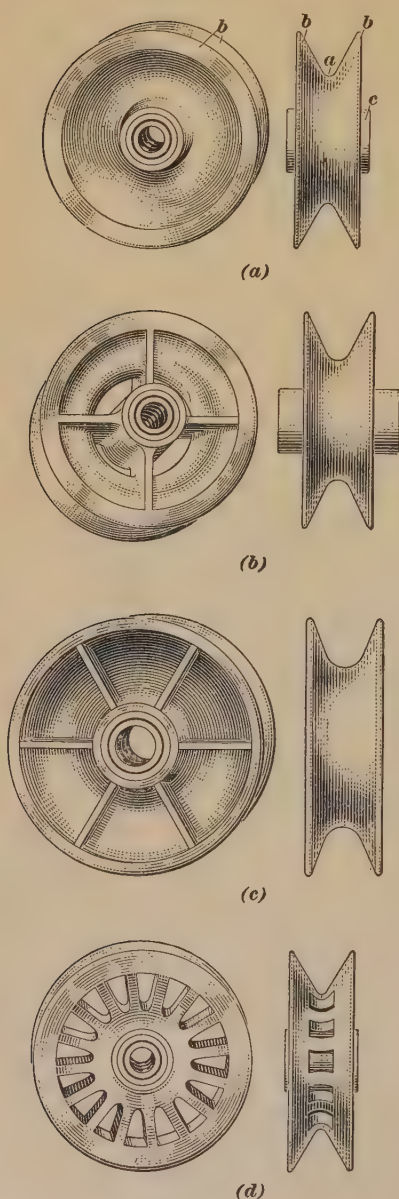


FIG. 25

given case to ensure both good collection of current and also a minimum of deterioration to the trolley wire. Trolley wheels are usually made of brass, gun-metal, or phosphor bronze, and the grade of metal must be chosen so that it is not so soft as to wear away quickly nor so hard as to cause undue wear of the trolley wire. The speed of the cars, the material and the disposition of the overhead wire with regard to the track, and the class and arrangement of the overhead fittings all affect the design of the trolley wheel.

35. Typical Trolley Wheels.—The diameter, width, and length of boss of the trolley wheel are settled in conjunction with the dimensions of the trolley head; the usual diameters vary from 3 to 5 inches, the most common sizes being $3\frac{3}{4}$ and $4\frac{1}{4}$ inches. The shape of the groove depends on the size and shape of the trolley wire and the design of the overhead ears. A trolley wheel with a special-shaped groove was shown in Fig. 23 (b), and wheels with

plain grooves are shown in Fig. 25 (a), (b), and (c). The wheel in Fig. 25 (a), of which *a* is the groove, *b* the flanges, and *c* the boss, is known as a *solid wheel*, being a gunmetal casting, simply turned up in the lathe to shape and afterwards bushed. A *spoke wheel* is shown in Fig. 25 (b), this wheel being somewhat lighter in weight than the former, but with a wider boss to suit a different pattern of head. A larger wheel, designed for running at high speeds, is shown in Fig. 25 (c); the groove is made wide, in order to give the trolley wire and ears sufficient clearance at curves, turnouts, etc. A *sleet-cutting wheel*, for clearing the trolley wire of sleet before cars fitted with the ordinary trolley wheel can run, is shown in Fig. 25 (d). The first car to run out over the line after a snowstorm would have a sleet-cutting wheel of this form; the perforations in the groove cut the sleet and allow it to fall out through the holes in the flanges.

36. Lubrication of Trolley Wheels.—Oil lubrication is never used for trolley wheels, because it is impossible to maintain a steady supply of oil to the bearing, and because any heating of the wheel or spindle due to the electric current will tend to dry up the oil. For fixed trolley heads, which allow the current to be collected from the wheel by a spring in the trolley head, *self-lubricating spindles*, for grease lubrication, have been used. An example of a self-lubricating spindle is shown in Fig. 26.

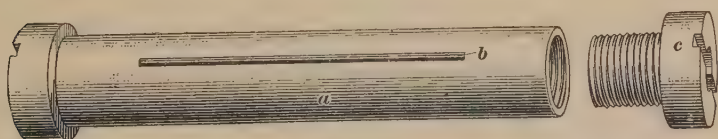


FIG. 26

The hollow spindle *a* is filled with vaseline, which reaches the bearing through the narrow slit *b* when the temperature rises sufficiently to melt it. The lubricant is retained by the screw cap *c*. For swivelling trolley heads, in which collecting springs, rubbing against the trolley wheel, cannot be used, neither grease nor oil lubrication is suitable, because of the heating effect of the current, and wheels utilizing solid lubricant must be used. The wheels shown in Fig. 25 are fitted with patent

oilless bushes. Grooves are machined on the inside and ends of each bush, and the grooves are packed with special solid lubricant, usually some form of graphite or graphite preparation. By this means wear is reduced to a minimum, and good electrical conductivity is maintained between the wheel and the spindle

37. Pressure of Wheel on Trolley Wire.—The pressure of the wheel against the trolley wire varies from 15 to 25 pounds, according to local conditions and the speed at which the car is to run. Too light a pressure will permit the wheel to jump off at the overhead fittings and at curves, while excessive pressure will wear all parts unnecessarily. Under ordinary conditions the pole should make an angle of about 45° with the car roof and the upward pressure on the wire should be about 20 pounds.

TROLLEY STANDARDS

38. Forms of Trolley Standard.—The device which holds the trolley arm and presses it upwards against the trolley wire is placed on the roof of a car and is known as the **trolley standard**. Its design depends on the type of car on which it is to be used. On double-deck cars without any top cover the trolley standard consists of a pedestal about 5 feet high, which must be insulated from the trolley wheel and connected to earth. On covered double-deck and single-deck cars the pedestal standard is not necessary, so a dwarf pattern is used; the trolley standard for a covered car need not be insulated. Springs are arranged in the trolley standard, so that the wheel carried on the trolley arm is made to follow the trolley wire and to maintain the necessary upward pressure on it if the height of the wire changes due to the contour of the ground or due to the necessity of passing under bridges, etc.

39. Double-Deck Trolley Standard.—In the B.T.H. double-deck, or pedestal, trolley standard, shown in Fig. 27, the cast-iron base *a* is bolted to the top deck of the car, and supports a fixed outer tube *b*, at the upper end of which the revolving head *c* is carried on ball bearings *d*. Pivoted to the revolving head at *e*

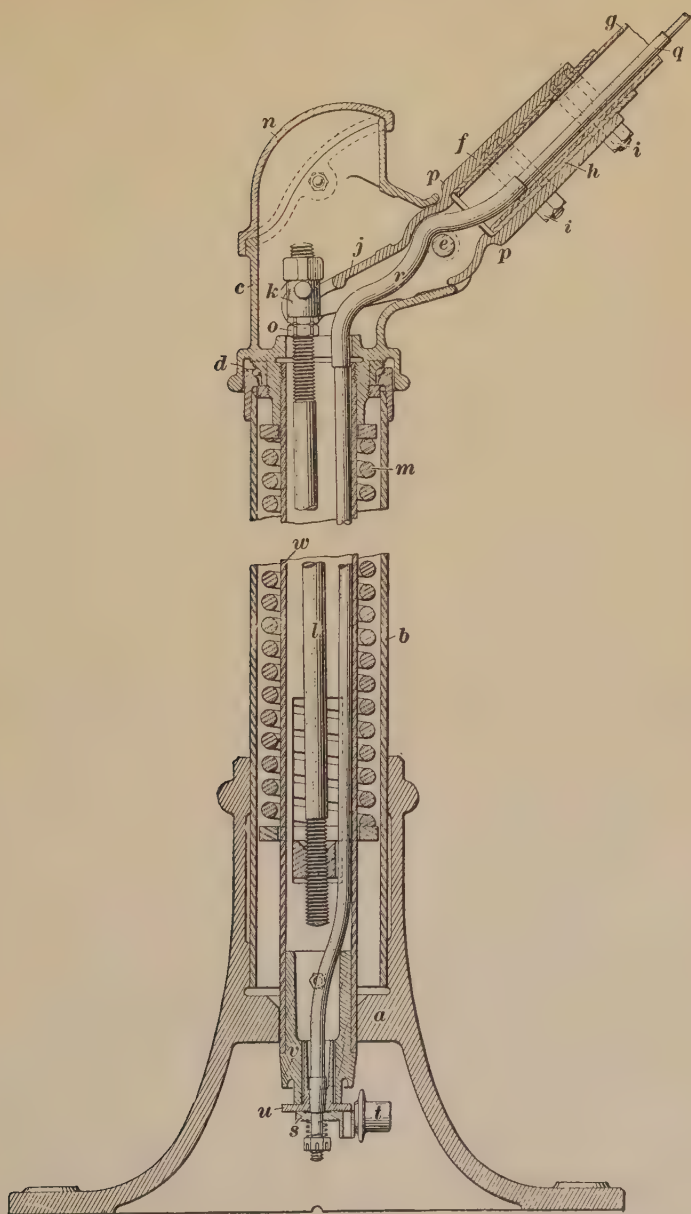


FIG. 27

is the working lever or pole socket *f*, into which the trolley arm *g* is clamped by means of the clamping plate *h* and bolts and nuts *i*. The lower end of the lever *f* is in the form of a hook *j*, which engages with the nut *k* and exerts a pull on the tension rod *l*, putting the spring *m* into compression when the trolley arm is depressed and maintaining an upward pressure of the trolley wheel. The compression of the spring *m* may be adjusted by removing the weather cap *n* and turning the nut *o* with a special key. Stops *p* prevent the trolley arm rising to an angle at which it might cause injury to the overhead work ; they also prevent its being pulled below the horizontal. The trolley cable *q* passes down the trolley arm from the trolley head, and is specially protected by a rubber tube *r* where it passes into the standard from the trolley arm. Special provision is made, by means of a revolving contact at *u*, so that the trolley arm may be turned in either direction and to any extent. The porcelain insulator *t* carries a fixed contact *s*, and this engages with a revolving contact *u* which is attached to the wooden insulator *v* and is turned with the revolving head by the inner tube *w* of the pedestal.

40. Dwarf Trolley Standards.—The trolley standards used for single-deck cars are sometimes similar to the top-deck pedestal

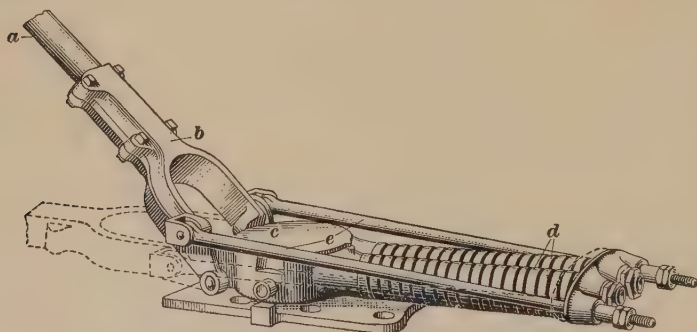


FIG. 28

standard, but much lower and often arranged with external springs. In this case it is not compulsory to insulate the standard from the trolley wire, and conditions of safety do not

require the mechanical parts to be enclosed. Where double-deck top-covered cars are used and the clearance under railway bridges is very little, a special design of dwarf trolley standard is used. The B.M.R. standard, shown in Fig. 28, is so arranged that, when the trolley arm is horizontal, no part of the standard is more than 4 inches above the trolley board on the roof of the car. The trolley arm *a* is clamped into a forked lever *b*, which is pivoted at the lower extremities to the revolving head *c*. Two helical springs *d* are held in a frame on the opposite side of the head to the trolley arm; the compression of these springs, transmitted to the lever *b* through the tension rods *e*, causes the trolley arm and wheel to exert the necessary upward pressure against the trolley wire when running. The dotted lines show the positions of the parts when the trolley pole is depressed to a horizontal position when passing under bridges, etc.

AUXILIARY APPARATUS

CAR RESISTANCES

41. The car resistance, or rheostat, carried on every car for starting purposes and for rheostatic braking, is an important part of the car equipment, since the operation of the car is dependent on the use of the resistance for all changes in speed that are made by the car driver. The resistance is usually made up of cast-iron grids, but in some cases the units composing it are coils of iron ribbon. In either case, the resistance is assembled on a suitable frame, and either hung under the car floor or placed on the driver's platform. The former position has been the more widely adopted, but it has the disadvantage that mud and water are thrown on the resistance from the car wheels. In the case of double-deck cars, there is generally sufficient room for the resistance to be put under the stairway, in which case this position is to be preferred.

42. **Grid Resistances.**—One form of cast-iron resistance grid is shown in Fig. 29. View (*a*) shows the shape of a single cast grid *a* and the method of supporting it on three bolts, shown

in cross-section, which are threaded through the lugs cast on the grid for this purpose. The middle lug is used merely for support to prevent the grid sagging, but the end lugs serve also for making electrical connection to the grid by means of the screws shown. As shown in view (b), the grids *a* are threaded

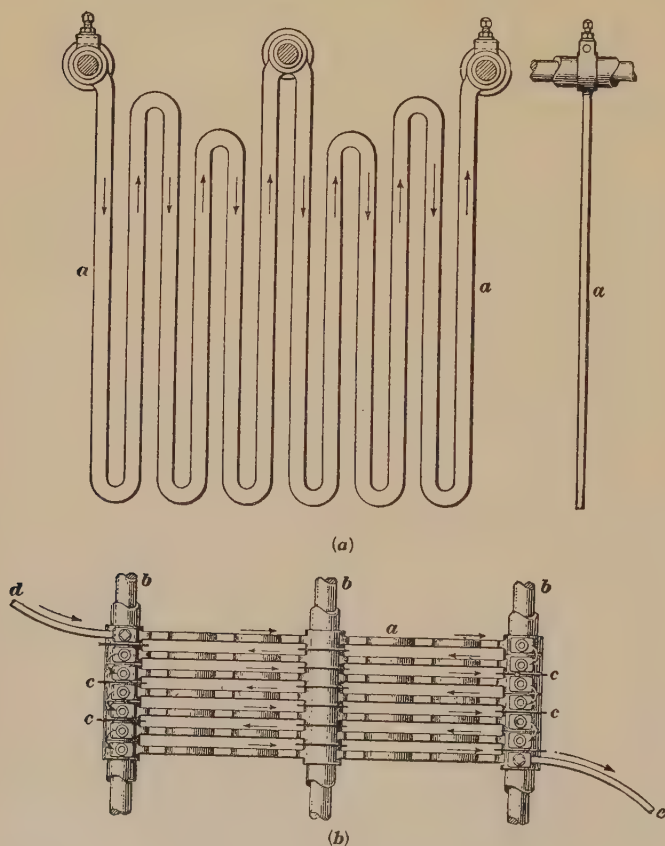


FIG. 29

on the insulated bolts *b*, and are insulated from each other by means of mica washers *c*. These washers *c* are so placed as to completely insulate the central lugs of adjacent grids, but successive pairs only of the end lugs are insulated, allowing electrical contact to be maintained between adjacent pairs when the whole

resistance is tightened up on the supporting bolts. The path of current through this section of resistance from the tapping lead *d* to the lead *e* is shown by the arrows, and is such that the current passes through every section of the resistance. The path of current through a single grid is shown by the arrows on the grid in view (a).

43. A later form of resistance grid, the B.T.H. type G T, is shown in Fig. 30. This form, shown in view (a), is adopted

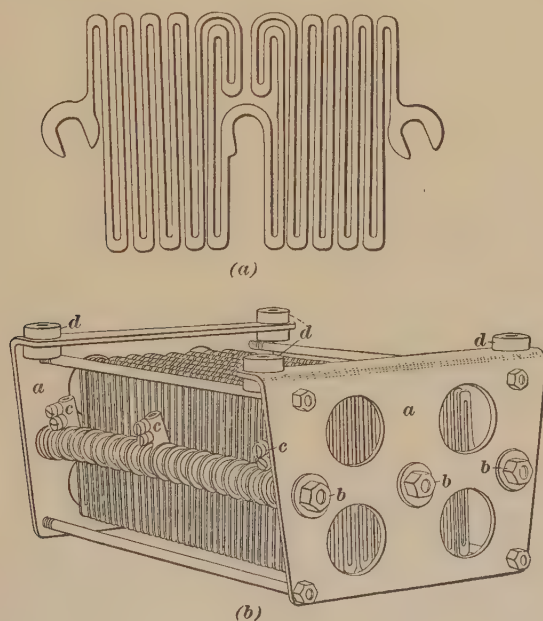


FIG. 30

in order to make the most effective use of the resistance material and, at the same time, to provide three supporting points on the centre line of the grid and thus obtain the maximum stiffness. The complete resistance, as assembled ready for mounting on the car, is shown in view (b). The end frames *a* are formed of steel plates, which are both stronger and lighter than cast iron, which is often used for the same purpose. Mica insulation is used throughout, mica tubes being used to insulate

the tie-bolts *b*, mica washers being placed between the resistance lugs. The brass terminals *c* provide means of making electrical connections to the resistance. The frame is suspended from the car floor by bolts which pass through holes *d*, bushed with fibre, in the feet of the end frames. Any section of the resistance may be withdrawn and replaced by simply slacking off the tie-bolts and slightly separating the grids at the desired points by sliding them along the bolts *b*.

44. Ribbon Resistance.—The Westinghouse circular pattern of car resistance is shown in Fig. 31. In this case each unit of the resistance consists of a spiral coil of iron band or ribbon, wound in the same manner as a clock spring and insulated with mica. Ventilation is provided for by leaving spaces between adjacent coils, when they are assembled between end plates on

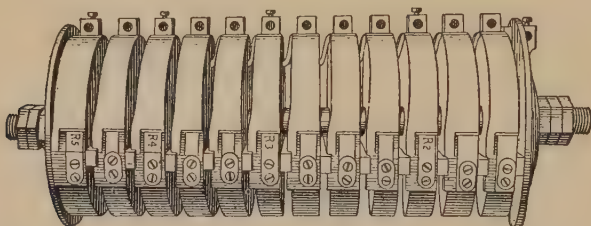


FIG. 31

a supporting bolt passing through the centres of all the coils. Terminals and binding screws are provided for making the necessary electrical connections, and the various points *R2*, *R3*, *R4*, *R5*, dividing the resistance into sections, are chosen to suit the particular controller used, and are marked with the respective letters and numbers for purposes of ready identification.

SWITCHES AND CIRCUIT-BREAKERS

45. Types of Switch.—The Board of Trade regulations require that an emergency switch shall be provided on every car and fixed so as to be conveniently reached by the driver in case of any failure of action of the controller. Since the driver operates the car from either end, according to the direction in which the

car is travelling, a switch is placed underneath the canopy over the platform at each end of the car. The driver thus has one switch always within reach. The two switches are connected in series in circuit with the trolley cable. One of the switches is arranged with a solenoid and automatic tripping device to open the circuit if the current rises to some predetermined excessive value; this is called the *automatic circuit-breaker*, or simply the *car breaker*. The plain switch at the other end of the car is termed a *canopy switch*. In some instances, fuses are connected in series with the two switches to open the circuit if the circuit-breaker should fail to act.

46. Westinghouse Canopy Switch.—The general appearance of the Westinghouse canopy switch is shown in Fig. 32. The switch is enclosed in a cast-iron case *a* provided with feet *b* for bolting the switch to the canopy of the car, and is protected by a cast-iron cover *c*, perforated at *d* to allow of the insertion of a screwdriver to tighten up the binding screws holding the cable connections. The handle of the switch *e* projects through an opening in the bottom

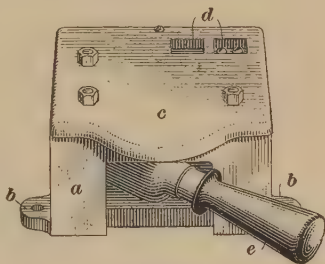


FIG. 32

of the case. The internal arrangement of the switch is shown in Fig. 33, in which view (a) shows a plan of the switch with the cover removed, and view (b) shows a cross-section through *A B*. The switch lever *a* is pivoted at *b* between two slate blocks *c*, *d*, which are separated by distance pieces *e*, *f* and distance tubes *g*. A wooden partition *h* is placed between the two arms of the switch lever, only one, *i*, of which is shown in view (a). Each arm carries a spring switch jaw *j*, which closes on the fixed switch blades *k*, *l* when the switch is in the on-position, as shown by the dotted lines in view (a). The line wires are brought into the top of the switch, through the wooden cover *m*, and are secured in the brass terminal blocks *n*, *o*, which are electrically connected to the switch blades *k*, *l*. Spring clips *p* are provided on each arm of the switch lever, which engage with the distance piece *f*

when the switch is open, and keep the handle *q* in the off-position. The cover *r* normally protects the working parts, and the feet *s* are provided on the base for fixing the switch to its support.

47. Westinghouse Car Circuit-Breaker.—It is not usually necessary to provide magnetic blow-out coils in connection with canopy switches, though some makers employ them. For automatic circuit-breakers, however, magnetic blow-out devices are always fitted, and, if possible, the same coil that is already

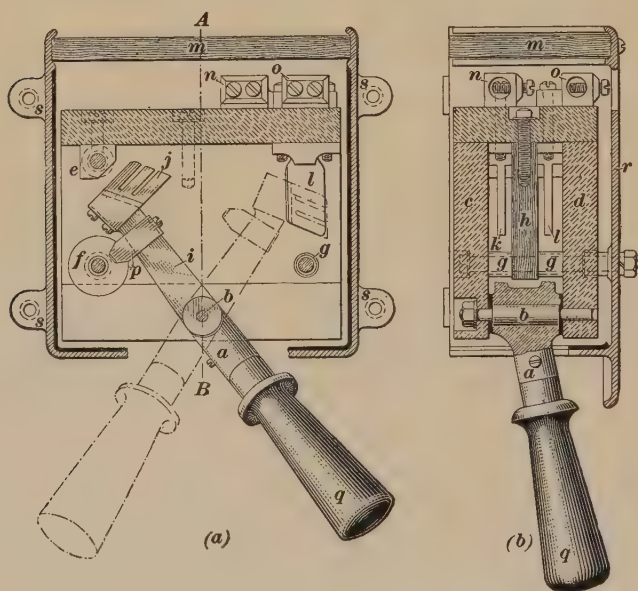


FIG. 33

provided to operate the tripping mechanism of the switch is utilized to produce the magnetic blow-out field. The Westinghouse automatic car circuit-breaker, which is shown in Fig. 34 (a) and (b), employs one solenoid coil for both purposes. The exterior of the circuit-breaker is shown in view (a). The working parts are enclosed in a cast-iron case *a*, provided with feet *b* for bolting to the support. A cast-iron cover *c* prevents access to live parts of the switch, but has an opening for the operating handle *d* and a flue *e* in which is extinguished any arc formed

between the contact points of the switch on breaking circuit. The small milled screw *f* is provided for adjusting the circuit-

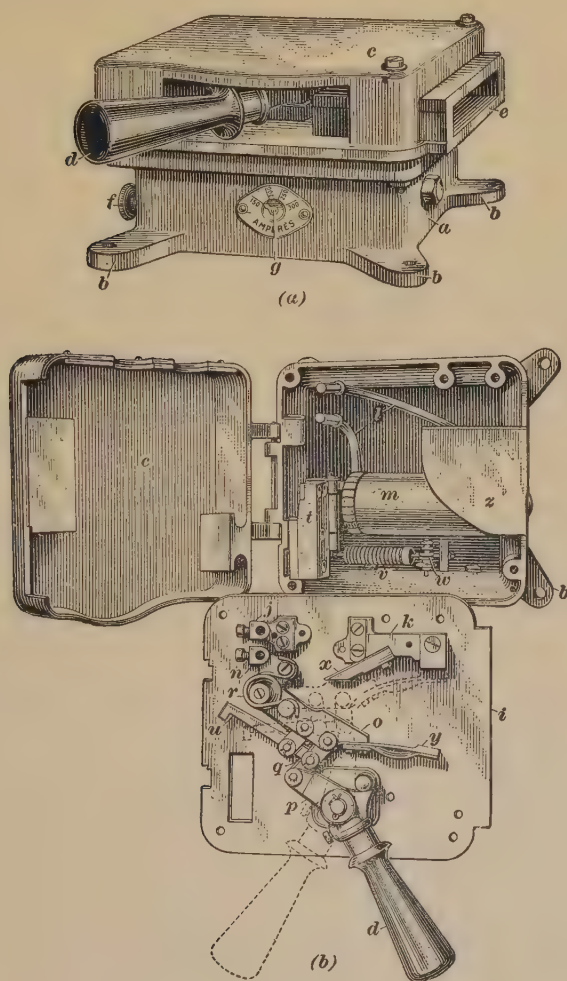


FIG. 34

breaker to open at a definite value of the current passing through it, and the index *g* shows on a scale the value of the current for which the circuit-breaker is set.

48. **Action of Westinghouse Circuit-Breaker.**—The arrangement of parts of the Westinghouse circuit-breaker is shown in Fig. 34 (*b*), in which the switch cover *c* has been thrown back, and the base *i*, which is of fireproof insulating material and carries the switch parts, has been removed. The trolley circuit wires are clamped into the terminal blocks *j* and *k*. A circuit is completed from *j*, through the leads *l* and blow-out coil *m*, to the terminal casting *n*, the switch arm *o*, and the terminal *k*, when the arm *o* is moved into the position of the dotted lines by the action of the handle lever *p* and togglejoint *q*. When the switch has been closed, the togglejoint is thrown past the dead centre, and the switch is held in a closed position by the toggle against the action of the spring *r*, which tends to open the switch. The switch can be opened by hand simply by moving the handle *d* to the right from the closed position until the togglejoint has passed its dead centre in the opening direction. The automatic features of the switch are obtained by the action of the rocking lever *t*, which is pivoted at its middle point, and one end of which acts as an armature of the blow-out solenoid *m*. When the switch is assembled, the lever *t* projects through a hole in the base plate *i*, and when the switch is closed, the lever *t* engages with a trigger *u*. If the current in the solenoid *m* reaches an excessive value, the armature of the coil is attracted against the compression of the spring *v* and the lever *t* pulls the trigger *u*, thus releasing the toggle and opening the switch. The adjustment of the circuit-breaker for different values of the actuating current is effected by a screw which alters the compression of the spring *v*, and the indicating pointer on the outside of the case is rotated by means of a worm and worm-wheel *w*. When the switch is closed, current passes from the arm *o* to the terminal block *k* through the laminated brush *x*; when the switch opens, arm *o* leaves brush *x* before the circuit is finally broken at the arcing finger *y*. By this means arcing is prevented from occurring at the main contacts, and is transferred to the arcing finger *y*, which can easily be renewed. A magnetic blow-out effect is obtained by means of a magnetic field set up by the blow-out coil *m* between the pole piece *z* and the cover *c* of the circuit-breaker.

49. Reliance Circuit-Breaker.—The general appearance of the Reliance circuit-breaker when the outside protecting cover is removed is shown in Fig. 35. The operating handle for opening or closing the switch is shown at *a* and the actuating coil and blow-out solenoid at *b*. The rocking lever *c*, one side of which acts as the armature of coil *b*, is the means of opening the circuit-breaker when the armature is attracted to the coil by an excessive flow of current. A flue *d*, in which any arc formed on opening the circuit can be extinguished magnetically, is provided at the top of the breaker.

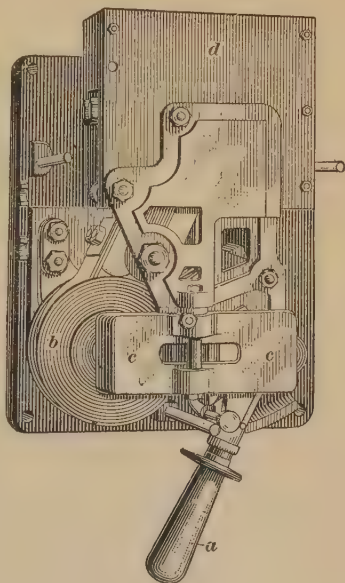
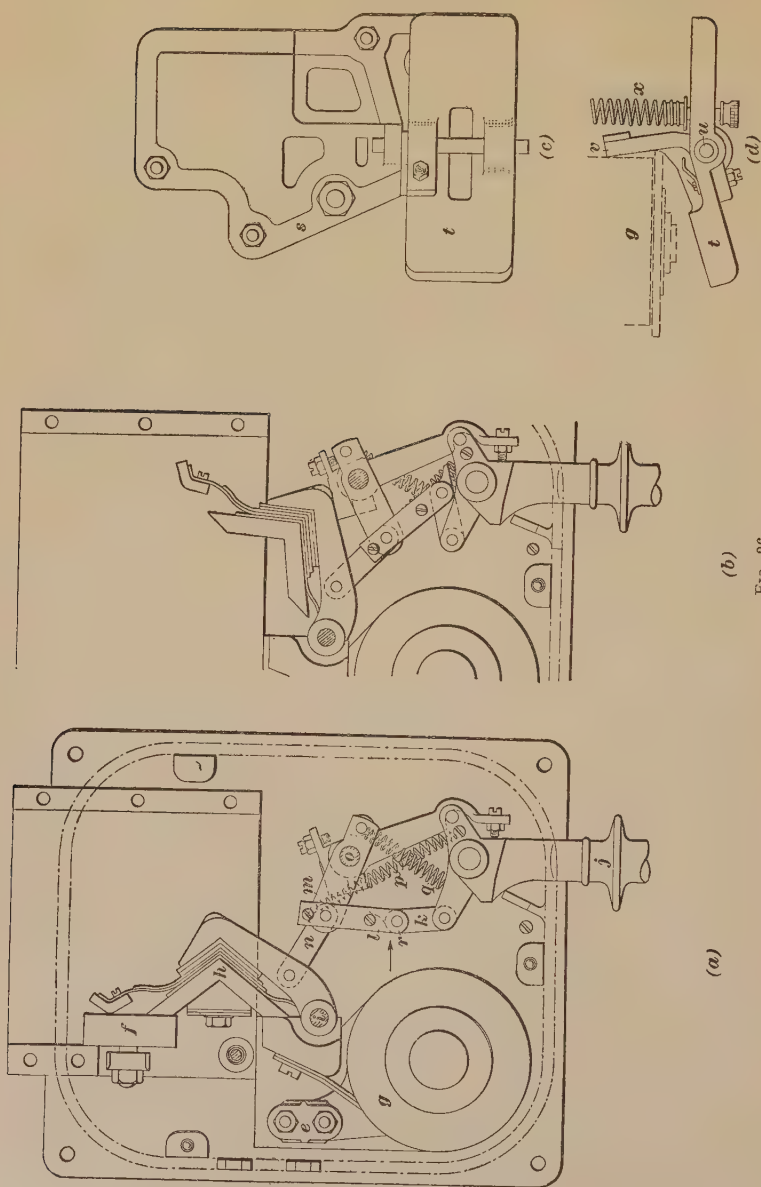


FIG. 35

50. Operation of Reliance Circuit-Breaker.—In Fig. 36 (*a*), (*b*), (*c*), and (*d*) is shown the actuating mechanism of the Reliance circuit-breaker. In views (*a*) and (*b*) the top plate *s* and rocking lever *t* have been removed, and are shown in views (*c*) and (*d*). View (*a*) shows the terminals of the circuit-breaker, to which the line wires are connected at *e* and *f*. From terminal *e* the circuit passes first through the winding of the blow-out coil *g* and thence, when the switch is closed, through the laminated switch blade *h*, the supporting lever of which is pivoted at the fixed point *i*, to terminal *f*. The switch may be opened and closed by the handle *j* through the links *k*, *l*, *m*, *n*, link *m* being pivoted at the fixed point *o*. The circuit-breaker is of the *loose-handle type*; that is, the handle is not connected rigidly to the switch blades, but only through links, which are arranged so that the switch cannot be kept closed so long as short-circuit conditions exist. Stability of the link mechanism is obtained, when the switch is closed, by means of the springs *p*, *q*; but when overload exists, the togglejoint *r* is knocked out in the



direction of the arrow, and the links take up the positions shown in view (*b*), at the same time opening the switch, quite independent of the position of the handle *j*. The device used for tripping the switch is shown in view (*d*). The rocking lever *t*, pivoted at *u*, has a striker *v* projecting below it, and when excessive current in the blow-out coil *g* tilts the lever *t* against the opposing pull of spring *x*, the striker *v* comes in contact with the togglejoint *r*, view (*a*), and trips the switch.

FUSES

51. Fuses Versus Circuit-Breakers.—At one time, the fuse alone was used to protect motor circuits from excessive currents. On many tramway systems the circuit-breaker has superseded the fuse, because a circuit-breaker can be set with a greater degree of certainty, and it is much easier and quicker to close a breaker than to replace a fuse. Circuit-breakers kept in proper repair and adjustment are certainly more reliable than fuses. On some large systems there is a tendency to revert to the practice of using fuses, but only in conjunction with circuit-breakers, because in many cases of failure of the circuit-breaker the controller has blown up, with disastrous results. A circuit-breaker in series with a fuse is a good combination on a car, as the circuit-breaker is normally a better protection than the fuse, but the fuse will prevent accidents should a short circuit occur and the circuit-breaker fail to operate.

52. Westinghouse Car Fuse.—In Fig. 37 is shown a type of fuse box introduced by the Westinghouse Company. The two parts *a*, *b* of the asbestos-lined iron box are hinged together through a togglejoint *c*. They are brought together by raising the handle *d*. In the bottom half are copper terminals with **V**-shaped grooves *e*, into which a piece of copper-wire fuse of suitable length is dropped. Registering with the **V**-shaped grooves *e* in the bottom terminals are **V**-shaped tongues *f* in the top terminals. On bringing the top and the bottom halves of the case together, by raising the handle bar *d*, the two pairs of **V**-shaped jaws automatically clamp the fuse in circuit. The

advantages of this type of fuse box are the low cost of maintenance and the certainty and rapidity with which a fuse can

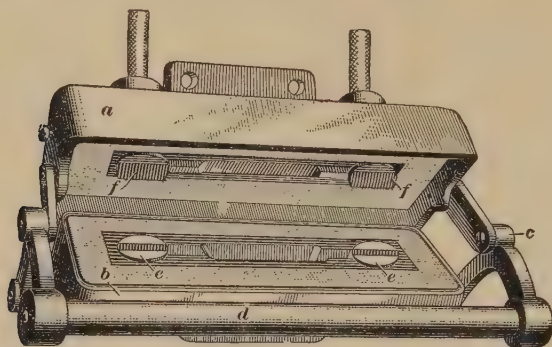


FIG. 37

be replaced without liability of shock ; the lower terminals are dead when the case is open.

53. Enclosed Fuses.—In Figs. 38 and 39 are shown **enclosed fuses**, which are so called because the fuse wire is enclosed in a hollow cartridge *a*, Fig. 38, made of some tough fibrous insulating material and provided with copper heads or terminals *b*. The space surrounding the fuse is filled with finely divided powder, such as sand, which extinguishes any arc formed

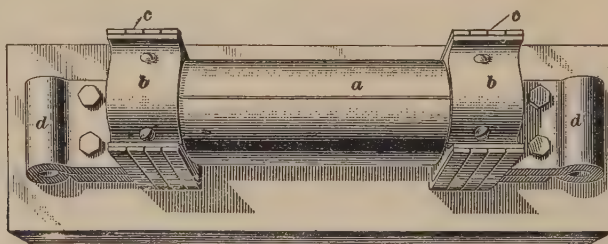


FIG. 38

by closing the passage, or a mixture of plaster of Paris and powdered borax, which, when the fuse melts, forms a flux with the molten metal, rendering it non-conducting and preventing the formation of an arc. The fuse cartridge is supported in spring jaws *c*, connected with terminals *d*, by means of which the fuse is connected in the circuit to be protected.

In Fig. 38 the parts are simply mounted on a slate base, but in Fig. 39 the whole device is enclosed in an asbestos-lined iron box *a*, provided with a lid *b* held closed by latch *c*. The trolley cable passes to the fuse-block terminals *d* through hollow insulating bushes *e*. Some enclosed fuses, instead of having contacts to fit spring jaws, have ordinary eye terminals that must be secured to their seats with screws. The screw connection is the more mechanical, but the spring-jaw construction is sufficiently safe and is much more convenient. To tell whether or not the enclosed fuse is blown, a small wire *f*, called the *telltale*, is sometimes connected in parallel with the enclosed fuse, but on the

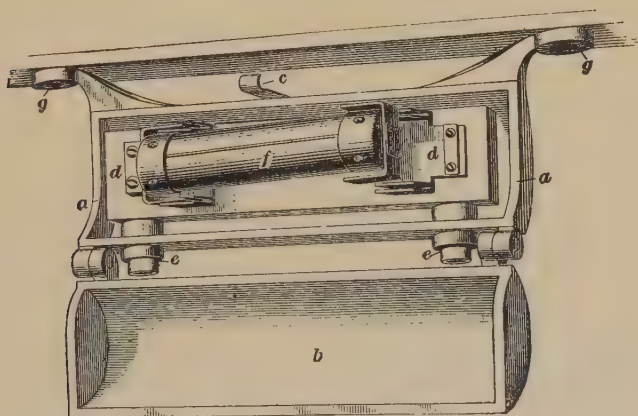


FIG. 39

outside of the cartridge. When the main fuse blows, the telltale burns out also. The enclosed type of fuse can be installed without danger of burning or shock by taking hold of the cartridge at the middle.

CAR METERS

54. Use of Car Meters.—It is the practice on some tramway systems to install a supply meter on every tramcar, and to keep records of the energy consumption, which can then be compared with the mileage run by the car. A check is thus kept on the general good condition of the car motors, controllers, gearing, etc., as well as on the skill of the driver in using the energy

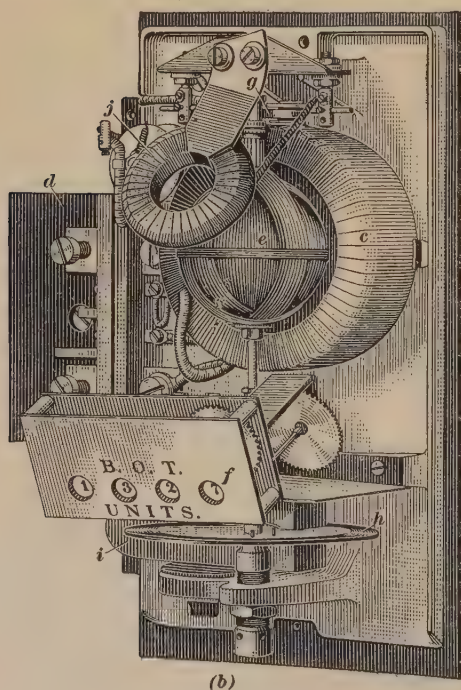
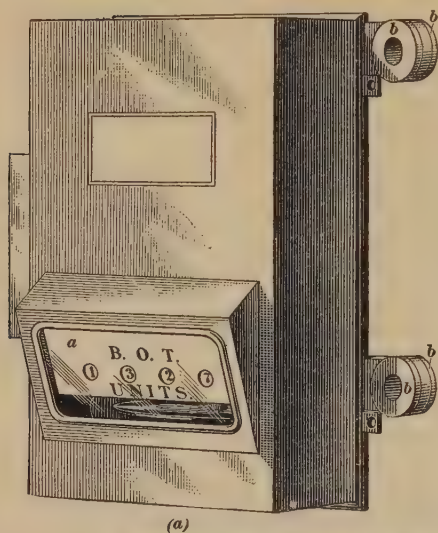


FIG. 40

economically or otherwise. The meters used are similar to stationary supply meters in general principle, but the arrangement and suspension of the parts is somewhat different, owing to the special conditions of duty.

55. Siemens Car Meter.—A Siemens car meter is shown in Fig. 40 (a) and (b). View (a) shows the meter complete, ready for mounting on the partition on the car. The consumption in Board of Trade units is registered in figures, and the reading can be observed through the window *a* in the cover of the meter. Rubber washers *b* are provided to cushion the meter when attached by means of screws to its support. In view (b) the cover of the meter is removed, showing the internal arrangements. The stationary coil *c* carries the main trolley current, the necessary

connections to the circuit being made on the terminal board *d*. An armature *e*, wound with a pressure winding and mounted on a vertical spindle, rotates in the magnetic field of coil *c*, and actuates the gear train of the counting mechanism at *f*. Current is led into the armature through the brushes and commutator *g*. The brake disc *h* and permanent magnet *i* provide the necessary retarding force to control the rotation of the meter. The jewelled bearings of the meter are spring-supported to protect the armature from vibration. The small fixed coil *j*, known as the *compensating coil*, is connected in series with the pressure winding of the armature and provides a magnetic field in the same direction as the current coil *c*, so that the meter will start with the smallest current in the main circuit.

LIGHTNING ARRESTERS

56. A car lightning arrester must be designed so as to extinguish automatically any arc due to the line current following the lightning discharge across the gap. It must be enclosed in a wooden box, in order to be protected from mud and water splashed up by the car wheels. Owing to the jolting and vibration to which it is subjected, the spark points of a car lightning arrester cannot be set for as small an air gap as on a stationary arrester, because of their liability to jolt together and produce a short circuit. No lightning arresters are needed on cars that run entirely in a tunnel or on a conduit system, but exposed trolley-line feeders and third-rail systems are protected in the usual manner. On ordinary tramcars, one arrester is used on the trolley end of the motor circuit, though two are better to ensure safety should one get out of adjustment. A lightning arrester having parts depending on gravity for action should be installed vertically. Where an external choking, or kicking, coil is used, or where a lightning arrester has three terminals, one of which leads to an internal choking coil, care must be taken to connect the lightning arrester so that the choking coil is in series with the motor circuit and not in series with the lightning-arrester air gap.

57. British Thomson-Houston Car Lightning Arrester.—The B.T.H. car lightning arrester, shown in Fig. 41, consists essentially

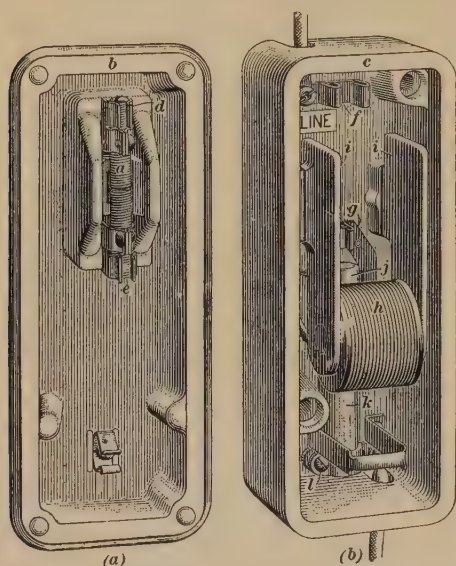


FIG. 41

of a single air spark gap connected up with a high resistance and a magnetic blow-out coil. A non-inductive high resistance limits the current that can flow across the air gap to earth from the supply system after a lightning discharge has passed; the leakage current passes round the blow-out coil in shunt with the resistance and produces a strong magnetic field that blows out the arc formed. The spark-

gap terminals *a* are attached to the cover *b* of the porcelain box *c*; as these terminals are threaded, the length of the air gap is readily adjusted while the terminals are disconnected from the live circuit. When the cover *b* is on the box, the circuit is closed, the contact pieces *d*, *e* on the terminals fitting into spring contacts *f*, *g* in the bottom of the box; the blow-out coil *h* is connected in shunt with a part of the resistance and is furnished with pole pieces *i*, which set up a magnetic field to blow out any arc formed between the sparking terminals. The high resistance *k* is held in the contact clips *j* and *l*. The trolley wire is connected to the contact *f* and the earth wire is brought in to the clip *l*.

LEAKAGE INDICATORS

58. Trolley-Standard Leakage Indicator.—In accordance with the Board of Trade regulations, an indicating device must be carried on double-deck cars without top covers, to give a warning

to the driver or conductor in case the trolley standard becomes electrically charged by means of a fault to earth on the trolley cable. This signal may be a red lamp which lights up if line current leaks to the trolley standard, or an audible signal such as a bell or buzzer. A special device developed for this purpose, known as the **Pringle trolley standard leakage indicator**, combines both an audible and a visible signal. In Fig. 42 (a) is shown the complete instrument; in (b) and (c) are shown the various parts when the cover has been removed. Under normal conditions the trolley standard is earthed through the leakage

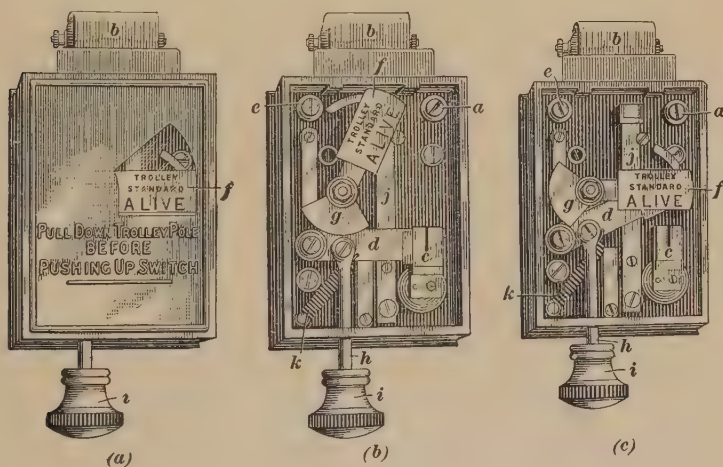


FIG. 42

indicator, the earthing wire from the standard being connected to terminal screw *a*, which is electrically connected through the buzzer *b* to the switch contact *c*, and thence through the switch blade *d* and a copper strip solenoid in the base of the indicator to the terminal screw *e* and directly to earth. As long as no current flows from the trolley standard to earth, through the leakage indicator, the indicating flag *f* is held in the position shown in view (b), and the earth connection cannot be broken, because the segment *g* attached to the flag *f* locks against the switch rod *h* to which the handle *i* is fixed, and prevents the switch blade *d* being opened.

59. Action of Pringle Indicator.—If the trolley standard becomes alive and an earth current, of any strength from a few amperes upwards, passes through the leakage indicator, the buzzer *b*, Fig. 42, sounds continuously, and the magnetizing current passing through the solenoid in the base of the instrument causes the armature *j* to be attracted toward the base. This releases the flag *f*, which drops to the horizontal position shown in view (*c*), and is visible through the window in the cover of the indicator, as shown in view (*a*). The switch blade *d* is kept closed by the tension of the spring *k*. On receiving the signal, the car must be stopped and the conductor must clear all passengers from the top of the car and remove the trolley arm from the wire, in order to break circuit. The handle *i* of the leakage indicator may then be pushed up, to open the earth connection, and the car driven to the depot for repairs. The danger-indicating flag remains in the horizontal position, and a catch interlocks the flag *f* and switch blade *d*, keeping the switch open, as shown in (*c*), until the necessary repairs are effected and the indicator is reset.

CAR WIRING

POWER WIRING

60. Power Circuits.—The connection of the various items of electrical apparatus on a tramcar is comprised in the **power wiring**, which includes all the motor circuits, and the **lighting wiring**, which deals with the circuits for external and internal lighting and illuminated signals. The actual arrangement of the power circuits varies with the type of equipment and the particular form of the apparatus used on the car. The most common case is the wiring of a car driven by two motors, which are controlled by one of two controllers, one of which is placed at each end of the car. A diagram of the wiring for one such wiring arrangement is shown in Fig. 43. The controllers *No. 1* and *No. 2* are placed one on each platform of the car, and all wires which are common to both controllers are grouped into two canvas hose *a*, *b*, which are carried from platform to platform under

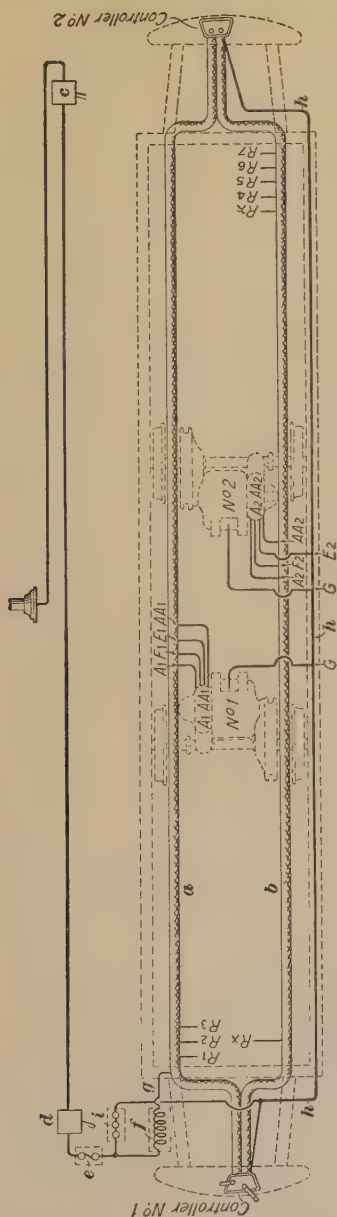


FIG. 43

the car seats. One hose *a* also contains a trolley cable, which is connected to the cable in the trolley standard through the canopy switch *c*, circuit-breaker *d*, car fuse *e*, and kicking coil *f*. The wire *g* leading from the kicking coil *f* to the hose *a* is termed the *trolley tap*. Various tappings are taken off the wires in each hose. From hose *a*, tappings *R1*, *R2*, *R3* are made to one frame of the car-starting resistance, under the floor of the car, while the tappings *A1* and *AA1* are connected to the armature leads of motor *No. 1*, and *F1* and *E1* to the field leads of that motor. Since the commutators and terminals of the two motors are on opposite sides of the car, all the other wires are placed in hose *b*. The tappings *Rx* are joined to the end of one part of the car resistance and to the beginning of a second portion, slung under the other end of the car. Tappings *R4*, *R5*, *R6*, and *R7* are connected to this second resistance. Tappings *A2* and *AA2* are connected to the armature leads of motor *No. 2*, and *F2* to one field lead of motor *No. 2*. A *ground*, or *earth*, wire *h* is also taken from one controller to the other, outside the canvas

hose. To the ground wire are connected the earth wire of the lightning arrester *i*, and the field lead *E2* of motor *No. 2*, while the ground wire is itself earthed on the frames of the two motors by tappings taken off at the points *G*.

CAR-LIGHTING WIRING

61. Arrangement of Lamps.—The lighting circuits on a car include the lamps for lighting the interior, the conductor's platform light, the dash or head light, and the lamps for illuminating the destination indicator. The Board of Trade also require a red light to be shown from the rear end of the car. This is usually arranged by fitting a red lens in the end partition of

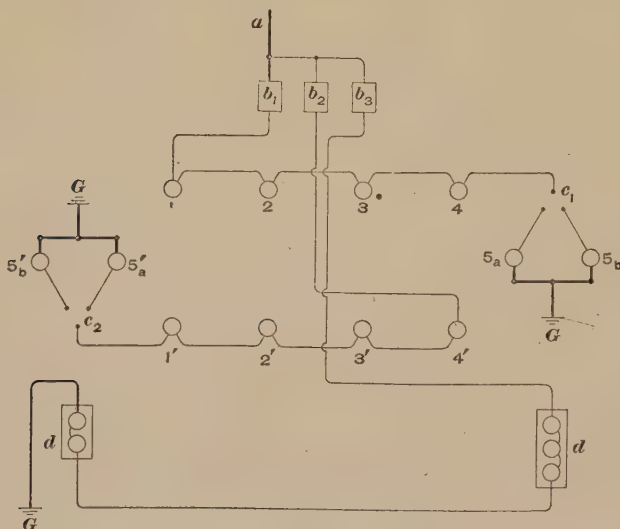


FIG. 44

the car and placing one of the inside lamps so that it will illuminate it. The dash or head light is only required on the front of the car when travelling, and the conductor's platform light only at the rear end, so that, as the car usually reverses at a terminus, arrangements must be made by means of three-point switches to light either the dash or the conductor's lamp at either end of the car. By this arrangement both dash lamps

may be lit in the case of fog, but when both dash lamps are lit the conductor's lamp is out.

62. Diagram of Connections.—There is no standard method of lighting a car, the lighting being suited to the requirements of each case, but in Fig. 44 is shown a common method of lighting a large double-deck car without top cover. In the case of top-covered cars an additional circuit of lights would be run. As the available trolley-wire pressure is 500 volts, the lamps are connected in circuits of five 100-volt lamps each. The wire a is a tapping from the trolley cable and is connected to the switches, or combined switches and fuses, b_1 , b_2 , and b_3 . The switch b_1 controls the inside lamps 1, 2, 3, and 4; the fifth lamp in the circuit is either the conductor's platform lamp 5_a or the dash lamp 5_b according to the position of the three-point switch c_1 . The circuit is grounded on the earth wire of the car at the nearest point G . Switch b_2 controls a similar circuit, consisting of lamps 1', 2', 3', 4', and $5_a'$ or $5_b'$, on the other side and end of the car, which are controlled by the three-point switch c_2 . The red lenses which show the red rear light may be placed in front of lamps 1 and 4'. Switch b_3 controls the two illuminated destination indicators d , three lamps being placed in one box and two in the other. The backs of the destination boxes are fitted with bull's-eyes, so as to light the top of the car.

CAR DEPOT

ARRANGEMENT OF CAR SHED AND REPAIR SHOPS

63. Location of Depots.—All cars are stored in depot car sheds at night or when not required for use; repair shops are usually connected with the depot to receive cars in the case of breakdown or for carrying out the ordinary maintenance repairs. In the case of a scattered district, it is not advisable to store all the cars in one shed, as this means a great waste of time in running out to the various districts when starting and returning from work. The *dead mileage* which is run means extra running

costs and wages. In these cases it is usual to have several car sheds in convenient places, with a central depot and repair shop, only light repairs being done at outlying depots, the heavy work being sent to the central repair shop for repairs.

64. Methods of Handling Cars.—The car shed may be entered from the tram lines on the main roadway by means of radiating and branch lines, forming a *fan*, or a double line may run directly into the car shed, and the cars distributed to the different lines inside the shed by means of a *traverser*. The fan entrance is suitable for small sheds, in connection with the overhead system of running, but in the case of large sheds, especially if in connection with the conduit system, complication is to a great extent avoided by the adoption of the traverser. A motor-driven platform at the floor level runs on rails laid in a pit across the car shed from one side to the other. As the cars come in they are run on to the platform, and traversed to the siding in which they are to be berthed, where they are run off.

65. Car Pits.—All the lines of rails in a car shed are arranged with pits between the rails under the cars, so that the car trucks and motors can easily be examined from below, and adjustments and small repairs easily carried out. The car pits should be from 4 to 5 feet deep, and are sometimes simply dug out and bricked at the sides. A better method is to excavate the whole area and lay a concrete floor, at a sufficient depth to form the bottom of the pits; the car rails are then laid on brick or cast-iron pillars, and a wood or reinforced-concrete floor is built between adjacent car sidings.

CAR REPAIRS

66. In small tramway systems, where there is only one depot and car shed, it is usual to have a small machine shop to deal with the necessary repairs. In large systems having many depots, the central repair shop handles the heavy repairs, such as are caused by serious collisions, and is also capable of thoroughly overhauling each car about every 12 months. The ordinary maintenance work carried out in the local depots includes

keeping all truck bolts tight, adjusting hand brakes, changing armatures, renewing bearings and pinions, changing flatted or worn-out wheels, repairing lights, bells, and trolleys, cleaning and repairing controllers, also the nightly cleaning of the cars. The work of replacing wheels in the depots is greatly facilitated if the pits are so constructed as to allow a short piece of rail to be taken out so that the wheels may be lowered into the pit by means of a jack.

67. General-Overhaul Shop.—The central repair shop usually includes a general-overhaul shop, a woodworking shop, blacksmith shop, paint shop, winding shop, and machine shop. A thorough annual overhauling is of very great importance to the successful running of the rolling stock. When the car comes in, the trucks are removed from the car body and the body is handed over to the bodymakers and painters for renewal of any woodwork and repainting, where necessary. The motors are removed from the trucks and the trucks are squared up and all brake-lever pins replaced where worn. Springs are renewed or set up, and the wheels, journal boxes, and bearings are attended to. The motor case is opened and the armature taken out; the motor case is cleaned and the field coils and connecting leads examined and painted with an insulating paint. The commutator is trued up, the armature is painted over, and the bearings renewed.

68. Woodworking Shop.—The essential tools in the woodworking shop are a circular saw, a band saw, a mortising machine, and a planer. This shop deals with the repairs to floors and roofs and any repairs to panels damaged by collisions.

69. Blacksmith Shop.—The blacksmith shop is fitted with the usual blacksmiths' tools, forges, and anvils, and deals with the straightening of truck stays, welding new ends on brake rods, and the many small repairs to the wrought-iron work on the cars.

70. Paint Shop.—The paint shop must be carefully enclosed from the other shops and kept clean, so as to prevent dust from settling on newly varnished cars. It should also be warmed by

hot-water pipes, so that the paint may dry quickly. Platforms or trestles should be erected alongside the cars, so as to render the upper portions easily accessible.

71. Winding Shop.—The winding shop must also be enclosed from the overhaul and blacksmith shops. It should contain the repair stands for the armatures, a banding machine, and a coil-winding machine, with formers for the various coils used, also a stove for drying out the armature and field coils. All defective armatures, field coils, and commutators are repaired in this shop; also the various cables used on the cars are repaired in it.

72. Machine Shop.—The machine shop contains the usual engineers' tools, drilling machines, planing and boring machines, a metal saw, and lathes for turning bearings, steel-tired wheels, and commutators. The emery grinder and wheel press are usually placed in an annexe where the wheels can be easily handled.

BRAKES AND BRAKE RIGGING

TRAMWAY BRAKES

MECHANICAL BRAKES

GENERAL PRINCIPLES OF BRAKING

1. If a tramcar is running on the level and the driving power is switched off, the car will continue to run for some time by virtue of the kinetic energy stored in it, but it will eventually come to rest owing to the friction of the wheels, axles, etc., and the resistance of the air. If it is desired to stop the car in a shorter distance or in less time, a retarding force must be applied by means of brakes. When the retarding force depends on the friction of brake blocks applied to the wheels of the car or to the track rails, the braking is purely mechanical. Alternatively the braking may be purely electrical, and then depends on the method of coupling the driving motors to the power-supply circuit or to resistances; sometimes mechanical and electrical braking effects are combined. In the case of mechanical brakes, the maximum retarding force which can be applied to stop a car depends on the friction exerted between the brake blocks and the car wheels or the track, and on the adhesive force between the wheels and the rail.

2. **Friction of Surfaces.**—If a horizontal force F , Fig. 1, is gradually applied to a block a resting on a plane surface until the block a moves, the applied horizontal force will be equal to the force due to the friction between the surfaces.

Let F = force required to produce motion, in pounds ;

W = reaction between surfaces, in pounds ;

μ (mu) = coefficient of static friction.

Then,
$$\mu = \frac{F}{W} \text{ or } F = \mu W$$

The quotient which results from dividing the force required to produce motion by the reaction between the surfaces, both being expressed in the same units, is known as the **coefficient of static friction**, or the **coefficient of adhesion**. Once movement has been started, however, the retarding force due to friction, and therefore the force required to maintain motion, are less than the force which was at first necessary to produce motion.

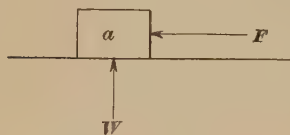


FIG. 1

Let F' = force required to maintain motion, in pounds ;

P = reaction between surfaces or pressure on brake block, in pounds ;

μ' = coefficient of sliding friction.

Then,
$$\mu' = \frac{F'}{P} \text{ or } F' = \mu' P$$

The **coefficient of sliding friction** is thus less than the coefficient of static friction. This has an important bearing on braking problems, since a greater braking force can be applied to the car wheels while they revolve at fairly high speeds than can be used at low speeds without causing the wheels to slide on the rails. If the coefficient of friction is referred to, without a specific statement as to whether static or sliding friction is meant, the coefficient of sliding friction is to be understood.

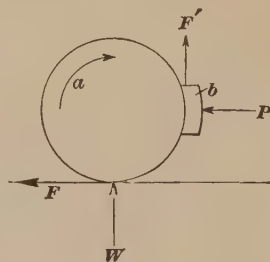


FIG. 2

3. Simple Wheel Brake.—If a wheel braked mechanically by means of a brake block b pressed against the wheel tire by a force P , as shown diagrammatically in Fig. 2, is rolling in the direction indicated by the arrow a , the other arrows will represent the forces acting

on the wheel. As the retarding force on the wheel is transferred to the rail head, the retarding force F' or $\mu'P$ at the wheel tire must not be greater than the total adhesion F , or μW of the wheel on the rail due to the reaction W . Unless the retarding force F' is less than F , slipping of the wheel on the rail will take place, and flat spots will be worn in the wheel tread. The coefficient of adhesion for a tram wheel on a clean wet rail is about .25, but this figure may be reduced to .1 if the rail is dirty or greasy.

EXAMPLE.—A four-wheeled tramcar weighing 10 tons is to be braked by means of one brake block on each wheel. If the coefficient of friction between the brake blocks and wheels is taken as .2, and the coefficient of adhesion between the wheels and rails is .25, with what pressure on the brake blocks will the wheels begin to slide on the rails?

SOLUTION.—The weight supported on each wheel is $\frac{10 \times 2,240}{4} = 5,600$ lb.

The adhesive force on the rail per wheel is therefore $F = .25 \times 5,600 = 1,400$ lb. The wheels will begin to skid when the retarding force on the wheel tire due to the brake is equal to the adhesion of the wheels on the rails. Then, the retarding force $F' = 1,400$ lb., $\mu = .2$, $P = 1,400$ lb. Therefore, the maximum permissible pressure on each brake block is

$$P = \frac{1,400}{.2} = 7,000 \text{ lb. Ans.}$$

4. **Negative Acceleration or Retardation.**—If the adhesion between the car wheels and rails in any given case is known, the maximum rate at which a car can be stopped can be determined as follows:

Let W = weight of car, or reaction between wheels and rails,
in pounds;

F = retarding force tending to stop the car, in pounds;

a = retardation of car, in feet per second per second;

g = acceleration due to gravity.

Then,

$$F = \frac{W a}{g}$$

But $\frac{F}{W}$ is equal to the coefficient of adhesion of the car wheels on the rails; therefore, $\frac{F}{W} = \mu = \frac{a}{g}$, or $a = \mu g$. If the

coefficient of adhesion is taken at $\cdot 25$, and since $g = 32\cdot 2$ feet per second per second, the maximum theoretical rate of retardation of the car that can be obtained without skidding must be $a = \cdot 25 \times 32\cdot 2 = 8\cdot 05$ feet per second per second.

5. As the maximum retardation that can be obtained depends on the coefficient of adhesion between the car wheels and rails, it is evident that any given car can be much more easily and more rapidly stopped when the rails are clean and in good condition, when the adhesion is high, than when the rails are dirty or greasy and the adhesive force is low. For the comfort of passengers, it is not usual to make an ordinary or service tramcar stop with a greater retardation than 3 feet per second per second; for emergency stops, however, the retardation must be as great as it is possible to obtain.

In the case of collisions, it is often necessary to be able to state the distance within which a car would stop after cutting off the power and applying the brakes. The distance which would be travelled can be calculated if the original speed of the car and the rate of retardation are known.

Let V = original velocity of car, in feet per second;
 a = retardation of car, in feet per second per second;
 S = distance travelled, in feet.

$$\text{Then,} \quad S = \frac{V^2}{2a}$$

EXAMPLE.—If a car is travelling at the rate of 10 miles per hour and a brake is applied which produces a retardation of 4 feet per second per second, in what distance can the car be stopped?

SOLUTION.— $a = 4$; $V = 10$ mi. per hr. $= \frac{10 \times 5,280}{60 \times 60} = 14\cdot 66$ ft. per sec. Then,

$$S = \frac{14\cdot 66^2}{2 \times 4} = 26\cdot 9 \text{ ft., nearly.} \quad \text{Ans.}$$

HAND-APPLIED WHEEL BRAKES

6. **Brake Blocks and Rigging.**—The brake blocks commonly used in practice for braking on the car wheels are of chilled cast iron, although many different metals and combinations of metals have been tried in order to combine the best braking effect with

the least wear on wheels and blocks. The blocks may be forced against the wheels, through a system of levers, either by hand pressure or by power. A hand-operated brake is usually fitted

to tramcars; the power-operated brake is always used on railways. The levers, rods, and gear generally that are intermediate between the operating handle and the brake blocks are called the **brake rigging**.

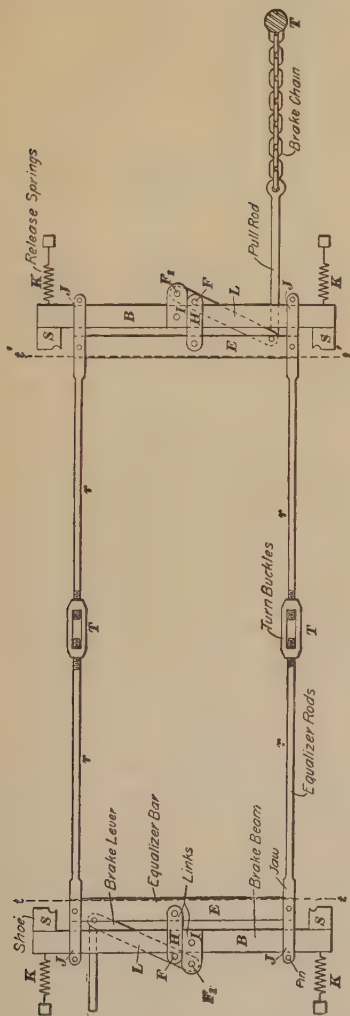


FIG. 3.

7. Single-Truck Hand-Brake Rigging.

A common form of single-truck brake rigging is shown in Fig. 3, where several of the parts are named. The brake beams *B* are supported at the ends, where they slide in cast-iron guides, called the *slide* or *brake-beam castings*, bolted to the side-frames of the truck. The equalizer rods *r* end in jaws *J*, to which the equalizer bars *E* are rigidly connected, but in which the brake beams can slide freely. The levers *L* transmit any pull on the pull rods or brake chains so as to draw the brake beams toward each other and apply the brake shoes *S* to the wheels.

The dotted lines *t*, *t'* indicate the position of the wheel tires. The links *H* are connected to the brake levers *L* and equalizer bars by means of pins. Links *I* connect the brake levers and brake beams; *F* is a pin round

which lever L and link H can move, and F_1 is a pin common to the lever L and brake beam B . In the illustration, the brakes are off and the shoes have been pulled away from the wheels by the release springs K . One end of each spring is fixed to the car truck and the other end to the brake beam. Turnbuckles T are provided in order to take up the slack as the brake blocks wear.

8. Brake Leverage of Single-Truck Rigging.—A fault of the usual arrangement of single-truck brake rigging is that the lever

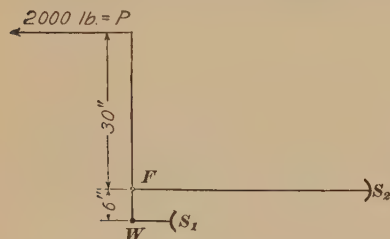


FIG. 4

construction tends to apply the brakes harder on the rear wheels than on the forward wheels. The leverage at one end of the truck rigging is shown diagrammatically in Fig. 4, where the brake lever, represented between P and W , is 36 inches long. The

force S_1 acts on the front brake beam, and the force S_2 acts on the equalizer bar which pulls on the rear brake beam; the force P acts on the brake pull rod. The pin joints for the respective beams are at F and W . If the rear brake shoes are against the rear wheels, the brake lever will pivot about F as a fixed point, and a pull of 2,000 pounds at P , in the direction of the arrow, will force the forward brake blocks against the forward wheels with a total pressure of $S_1 = \frac{30}{6} \times 2,000 = 10,000$ pounds. If, however, the shoes are against the forward wheels, the lever will pivot about W as a fixed point, and a pull of 2,000 pounds at P will pull the rear brake blocks to the rear wheels with a force of $S_2 = \frac{36}{6} \times 2,000 = 12,000$ pounds, a difference of 2,000 pounds when compared with the pressure of the forward brake blocks. This occurs because the forward beam is moved by a lever of which the fulcrum is between the points of application of the applied force and the load, whereas the rear beam is operated by a lever of which the point of application of the load is between the fulcrum and the applied force.

9. Double-Truck Brake Rigging.—In Fig. 5 is shown a type of double-, or bogie-, truck rigging much used. The tendency

to apply the rear brakes harder than the forward ones is

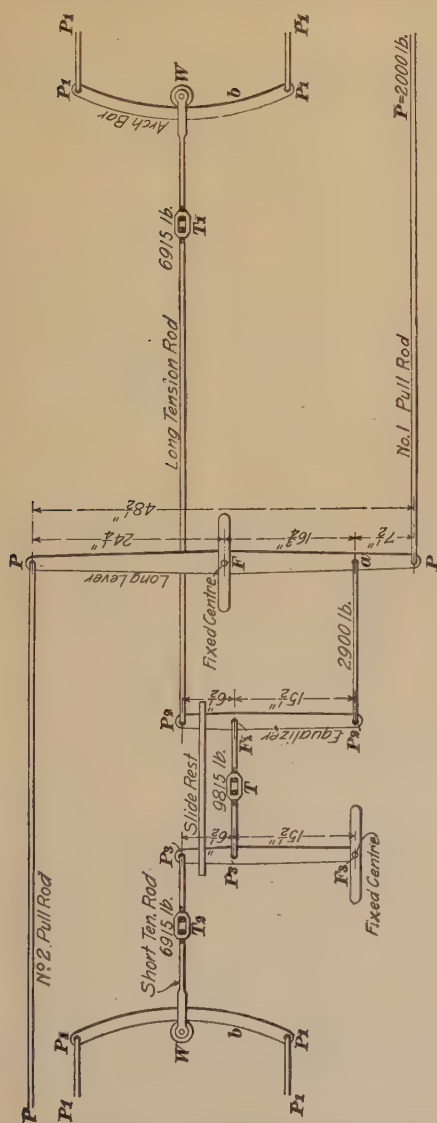


FIG. 5

overcome by the use of an extra equalizing lever that cannot easily be applied to single-truck riggings. In this rigging, the pull on pull rod No. 1 or No. 2 is transmitted through the brake levers and tension rods to arch bars *b*, one on either truck. The shape of the arch bars, and the arrangement of wheels *W* on the tension rods, running on the arch bars, enable the brakes to be applied whatever the relative positions of the swivelling trucks. Turnbuckles *T*, *T*₁, *T*₂ serve to take up slack in the various bars. Both the fulcrum *F* of the long brake lever and the fulcrum *F*₃ of one of the equalizing levers are fixed to the car body. The other equalizing lever is connected by a link to a point *a* on the long brake lever. Levers *P*₂ and *P*₃ are supported by a slide rest that

permits horizontal sliding motion, and they are connected by a

turnbuckle rod attached to them at the points F_2 and P_3 . The rigging is indicated in the position of best leverage, the brake blocks being on the wheels.

10. Brake Leverage of Double-Truck Rigging.—A pull of 2,000 pounds exerted on pull rod No. 1, causes the lower end of lever $P F P$ to move to the right and thereby exert a pull on rod $a P_2$. As the length of the long arm $P F$ is $24\frac{1}{4}$ inches and of the short arm $16\frac{3}{4}$ inches, the pull on $a P_2$ is $\frac{24\frac{1}{4}}{16\frac{3}{4}} \times 2,000 = 2,900$ pounds, nearly. As rod $a P_2$ is connected to the equalizing lever P_2 , this pull is applied to the lever P_2 , of which the long arm is $15\frac{1}{2}$ inches and the short arm $6\frac{1}{2}$ inches, the fulcrum being at F_2 . As the power is applied to the long arm, the pull on the long tension rod is $\frac{15.5}{6.5} \times 2,900 = 6,915$ pounds.

The pull on the turnbuckle rod $F_2 P_3$ is $6,915 + 2,900 = 9,815$ pounds, which, if applied directly to the short tension rod leading to the arch bar of the rear truck, would apply excessive braking pressure. To avoid this inequality, a second equalizing lever, pivoted at F_3 , is introduced, the effect of which is to make the pull on the short tension rod 6,915 pounds, thereby ensuring that the braking pressure on both trucks shall be the same.

11. Arrangement of Truck Rigging.—Rods P_1 , Fig. 5, at the extremities of the arch bars b , are the truck pull rods that apply

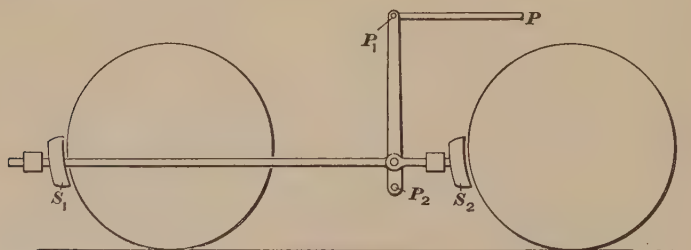


FIG. 6

the braking pressure to the truck levers. Fig. 6 shows the truck rigging on one side of the truck. A pull to the right on rod $P P_1$

forces the brake shoes S_1 , S_2 against their respective wheels, P_2 being a fixed point on the car truck.

12. Maximum-Traction Brake Rigging.—The brake rigging attached to the car body is the same for **maximum-traction trucks**

as for ordinary double trucks, but the truck rigging must be modified so that the greater braking pressure is applied to the large wheels, the axle of which supports more than two-thirds of the weight carried by the truck. Fig. 7 shows the truck rigging used on one side of the Peckham maximum-traction truck. The truck pull rod is connected to the upper end of

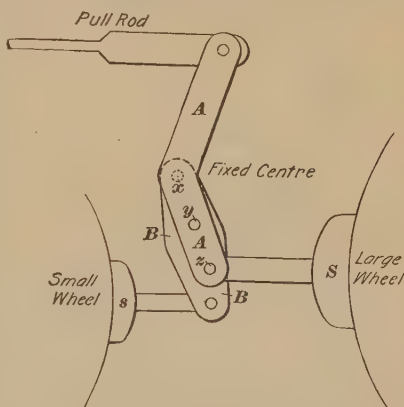


FIG. 7

a bent lever A , while the lower end of the lever is attached to a push rod that operates the shoe S of the large wheel. Lever A has no stationary fulcrum, but is pivoted at y to lever B , and the latter has a stationary fulcrum at x . The lower end of lever B operates a push rod that applies the brake shoe s to the small wheel. A pull to the left on the pull rod turns lever A in a counter-clockwise direction on y as a centre, thereby applying the shoe S to the large wheel; z then becomes a centre round which lever A continues to turn, thereby moving pivot y to the left and causing lever B to turn in a clockwise direction on fixed centre x , the lower end of B forcing shoe s against the small wheel. The movements of the large and small shoes, in practice, take place simultaneously.

13. Hand-Brake Spindle.—The usual method of exerting a force on the pull rod of a hand-brake rigging is by means of a handle on a vertical spindle that winds up a chain attached to the brake pull rod. The vertical spindle is carried by brackets attached to the dash of the car; when the spindle is turned by the handle the chain is wound up on it and pulls on the brake

rod. In the Peacock brake spindle, shown in Fig. 8, the chain *a* is not wound directly on the spindle *b*, but is wound on a spiral cam *c*. The cam is suitably grooved to take the chain, and is

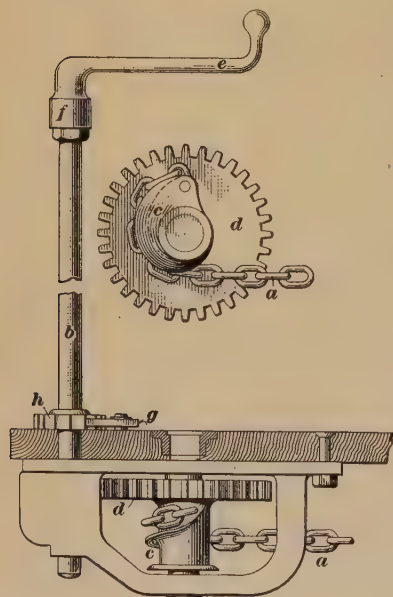


FIG. 8

geared to the spindle, the larger toothed wheel being shown at *d*. The cam is shaped so that when the handle *e* is first turned the slack of the chain is rapidly taken up on a large radius; but when the brake blocks reach the wheels and a greater leverage is required, the radius of the cam is much smaller. A ratchet is provided in the handle at *f*, so that the spindle can be turned with the brake handle *e* always in the most convenient position, and where the pressure on the handle can be most effectively applied. The brake is kept in the full-on position or at any intermediate point when

the car is stopped or is descending long hills by means of the dog *g*, which engages with a ratchet wheel *h*.

TRACK BRAKES

14. Instead of utilizing the friction of brake blocks on the car wheels in order to retard a car, the braking may be effected by the mechanical application of brake blocks, or **slippers**, bearing directly on the track rails. A brake depending on this principle is known as a **track brake**, and the pressure of the brake blocks on the rails may be applied either by hand or by air pressure. When the gradients on the line exceed 1 in 15 over any considerable distance, the regulations of the Board of Trade require the provision of a slipper brake or other track brake on every car.

The slipper is made of oak, beech, or other hard wood, and as it picks up grit from the road surface the rubbing surfaces between the slipper and rail have a coefficient of friction much greater than that of an iron brake shoe rubbing on a wheel.

15. Use of Track Brakes.—Track brakes are very useful on routes over long hills. When descending hills, the brake slippers are screwed down on to the rail head with a pressure suitable to the gradient; the speed can thus be regulated very well, and the danger of the car running away is practically eliminated. As a further safety precaution, it is usual to arrange one or more compulsory stops on long and dangerous hills, in order to prevent the car getting beyond control. Stops are effected by means of the ordinary hand-operated wheel brakes. The pressure of the slipper brake on the rails must not be so great as to take the weight of the car off the wheels, and the leverage is generally arranged so that not more than about 40 per cent. of the weight can be taken on the slippers. There is then sufficient weight left on the wheels to obtain some further braking effect by means of wheel brakes, but in any case the reduction of weight on the wheels is a disadvantage in all mechanical track brakes, as the adhesion of the wheels is decreased when the track brakes are applied, and the wheels are therefore more readily locked by the application of the wheel brakes.

16. Combined Wheel and Track-Brake Spindle.—The Peacock combination spindle for hand-applied wheel and track brakes is shown in Fig. 9 (*a*) and (*b*). The wheel brake is applied by the handle *a*, Fig. 9 (*a*), spiral cam *b*, and chain *c*, as already described. The track brake is applied by rotating the hand wheel *d*. This wheel is mounted on a sleeve which passes over the wheel brake spindle. The sleeve drives a pinion *e* and a pair of bevel wheels *f*. The rotation of the screw *g*, view (*b*), moves a nut *h*, to which the pull rod of the track brake is attached, and applies the brake slippers to the surface of the rail with the amount of pressure required.

17. Pneumatic Track Brake.—Instead of using hand power to apply the track brakes to the rail surface, compressed air may

be used, and a better braking effect obtained with less effort on the part of the driver. In the Hewitt & Rhodes track brake, each slipper is applied to the rail by means of a compressed-air cylinder and piston, two- or four-brake cylinders being fitted to a single-truck car, according to its size and the gradients of the line. Four cylinders, one on each side of each bogie, are applied

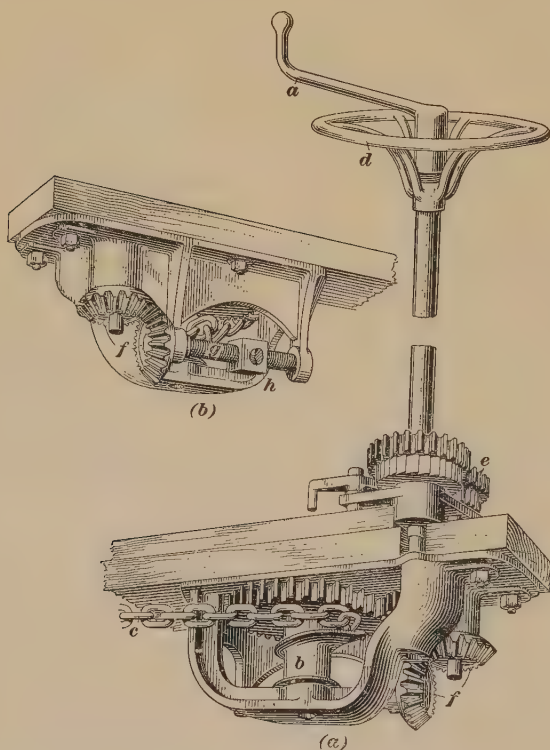


FIG. 9

to a double-truck car. An air compressor is carried on each car and is driven from the car axle by means of a chain gearing, or, in the case of maximum-traction trucks, the compressor may be mounted directly on the pony-wheel axle.

18. Pneumatic-Brake Cylinder.—Each brake cylinder is self-contained, and in the event of failure of one brake the others

are still available. A cross-sectional view of a pneumatic track brake is shown in Fig. 10. The air cylinder *a* is carried on a base *c*, which is bolted to the truck.

The piston *d* of the cylinder is connected by a plunger *e* to the toggle-levers *f*, which are pivoted to a bracket carried down from the base by steel pins *g*. The levers carry the cast-steel holder *h*, in which is held the brake block *b*

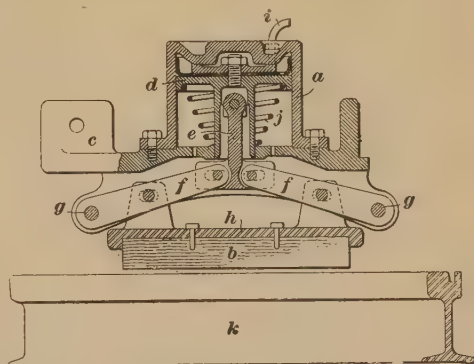


FIG. 10

of oak, elm, or other hard wood. When compressed air is admitted to the top of the cylinder, through the air inlet *i*, the piston is driven down against the pressure of the spring *j*, and, acting through the toggle-levers *f*, presses the brake block on to the rail *k*. A pneumatic track brake, unlike a hand-operated brake, causes very little stress on the car body, since the air in the cylinder acts as a cushion to prevent shock as the brake block passes over inequalities in the track.

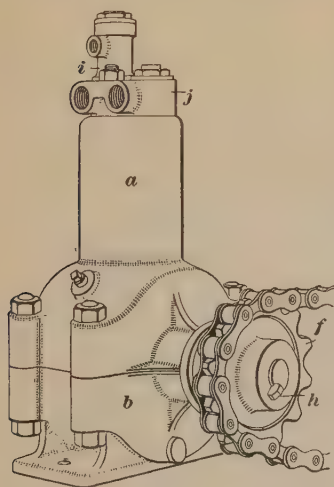


FIG. 11

19. Compressors for Pneumatic Brake.—The general appearance of the air compressor for the Hewitt & Rhodes brake is shown in Fig. 11. Sectional views are shown in Fig. 12, corresponding parts being given the same reference letters in the two illustrations.

The body of the compressor consists of two castings *a*, *b*, bolted together, the former being the cylinder and the latter

serving to enclose the crank and form an oil chamber. The crank *c*, Fig. 12, and the crank end of the connecting-rod *d*

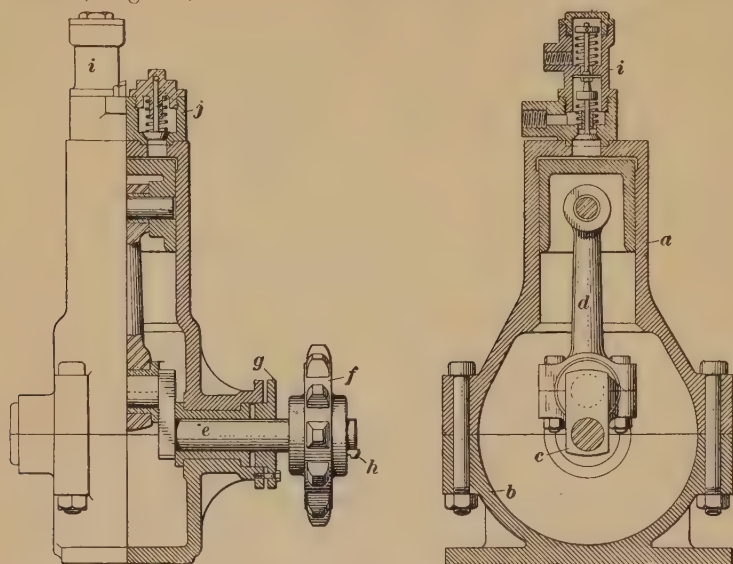


FIG. 12

normally work in an oil bath. The crank-shaft bearing *e*, next the chain wheel *f*, is provided with a stuffingbox *g* to prevent

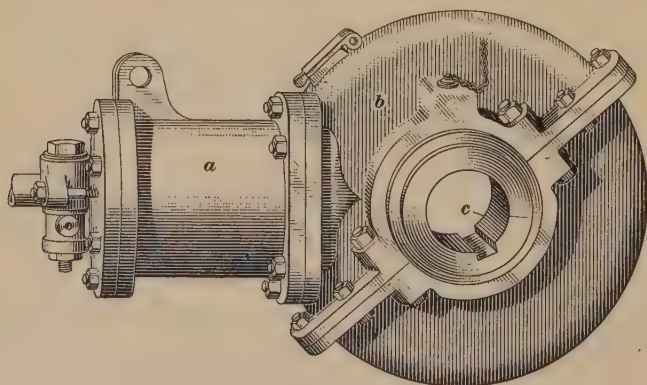


FIG. 13

the exit of oil or the entrance of dirt. The chain wheel is keyed to the shaft by means of a key *h*. The inlet and exhaust

valves *i* and *j*, respectively, are fixed to the top of the cylinder. In order to economize the driving power, and to prevent unnecessarily heating the cylinder when the maximum pressure is attained in the storage reservoir carried on the car, the inlet valve is lifted on the compression stroke and the compressor does no work on the air. In the direct-driven air compressor shown in Fig. 13 the cylinder *a* is placed horizontally to economize headroom, and the crank-case *b* is split diagonally and bolted together. Instead of being driven from a crank, the piston is driven from an eccentric bored out at *c* to fit the car axle to which it is keyed.

20. Arrangement of Pneumatic - Brake Equipment.—The method of connecting up the various parts of a pneumatic-brake equipment is shown in Fig. 14. The compressor *a* delivers air at the required pressure to the reservoir *b*, both compressor and reservoir being carried beneath the car floor. From the reservoir the air passes into the reservoir pipe *c*, which is maintained

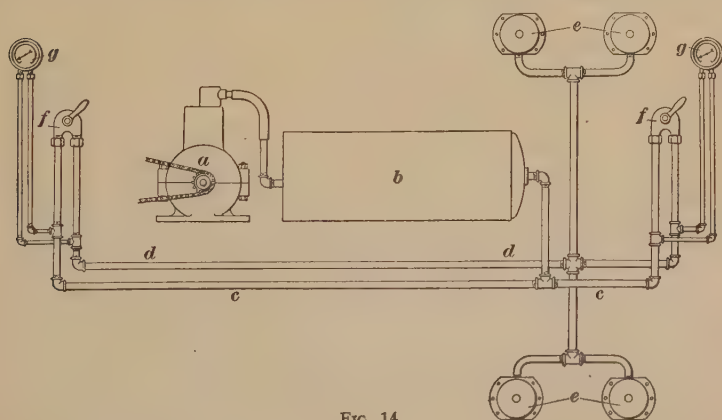


FIG. 14

at reservoir pressure. Air can be admitted from the pipe *c* to the brake pipe *d*, and thence to the brake cylinders *e*, by means of either of the driver's valves *f*, one of which is mounted on each platform of the car, together with a duplex pressure gauge *g* to indicate to the driver the available braking pressure in the reservoir and also the pressure in the brake cylinders.

ELECTRIC BRAKES

21. Rheostatic Brake.—In addition to providing mechanical brakes on a tramcar, it is the general practice to arrange some means of braking the car electrically also. The most common method is to connect the car motors, after disconnecting them from the supply, so that they will act as generators and send current through the whole or a part of the car-starting resistance. The controller which is normally used to operate the car motors is arranged, in this case, so that one movement of the handle will both cut off the power from the motors and connect the motors in such a way to the starting resistance that a braking effect is exerted to stop the car. This arrangement is known as a **rheostatic brake**.

22. Connections for Rheostatic Brake.—The back E.M.F. of a motor opposes the flow of current through the armature from the line, and if the motor is simply disconnected from the line, but is kept revolving in the same direction as before, the back E.M.F. will tend to set up a current in the opposite direction to the original motor current. In the case of a series motor, the residual magnetism of the field will still set up a small E.M.F., which will tend to send a current through the field in the opposite direction to the original exciting current; if the field circuit is closed through the motor armature and a resistance, the motor

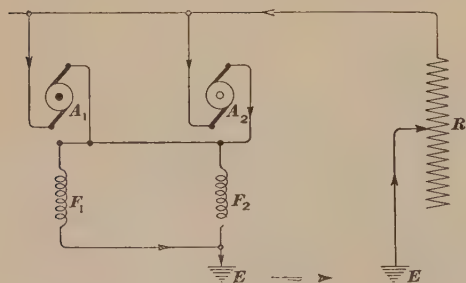


FIG. 15

field will not build up as a generator, but will be demagnetized entirely. In order to make the series motor act as a generator, either the field or the armature connections must be reversed; in practice, it is usual to reverse the armature

connections. The ordinary connections for rheostatic braking with two motors are shown in Fig. 15. The two motors are

connected in parallel with each other, with the connections to the armatures A_1 , A_2 reversed, and in series with the car-starting resistance R , through the earth wire E of the car. An equalizing wire is connected across the terminals of the field windings F_1 , F_2 , next to the armatures, in order to ensure, as far as possible, that the field strengths and currents of the two machines are equal.

23. Another method of electrical braking which is sometimes used in making an emergency stop is to change the connections by means of the controller, so that the motors will endeavour to drive the car backwards. The connection of a motor with armature A and field F when driving the car forwards is shown in Fig. 16 (a), and when reversed for an emergency stop in Fig. 16 (b). The motor does not act as a generator to return current to the line T when connected as in (b), but the armature E.M.F. assists the flow of current from the line to the earth E , and the current, and therefore the motor torque exerted to stop the car, are both greater than normal. As this method puts very severe stresses on the equipment, it is resorted to only to avoid collisions when running at fairly low speeds with the two motors of the car in series. If the speed of the car is high enough, the automatic switch on the car will probably open owing to the excessive current. If when this happens the circuit-breaker is not replaced, but the controller handle is moved to a parallel position, the motors being still connected for the reverse direction, a third method of braking is obtained, due to the motors being coupled together in parallel but without any equalizing connection across the field-coil terminals. Under these circumstances, as no two series motors generate exactly equal back E.M.F.'s, the motor generating the higher voltage will force a current through the lower-voltage motor and will reverse it. The motors will then be coupled in series through one another, one acting as a generator to drive the other as a motor in the opposite direction to that in which it has been

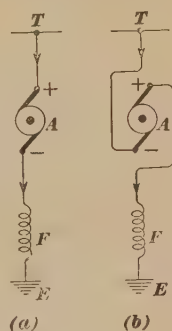


FIG. 16

running. As in the case of the reversal of the motors, this method is a severe one, and should be used only in a case of emergency. A car cannot be brought to a standstill by means of the rheostatic brake alone, because the current supplied by the generative action of the motors, and consequently the braking force, depends on, and decreases with, the speed. In some instances, the generative action of the motors is used to supply current to special magnetic brakes, thus giving double braking action while the car is in motion.

24. Regenerative Braking.—If, instead of connecting a resistance across the terminals of a series motor which is connected to act as a generator, the motor is shunt-wound, and the terminals are connected to the supply circuit, current may be delivered to the mains providing the speed and field flux of the generating machine are adjusted so that the back E.M.F. generated is slightly above the line P.D. The retarding action on the armature of the generating machine is the same as though a rheostat were used, but the power, instead of being wasted, may be used in other parts of the system. Such a system of braking is known as a **regenerative, or recuperative, system**.

Regenerative control and regenerative braking are used in tramway work in connection with direct-current shunt motors, and in electric-railway traction on the three-phase alternating-current system. Regenerative or rheostatic systems of braking are open to the objections that extra work is thrown on the motors, and unless the motors used are larger than would otherwise be required this may result in overheating them. Moreover, the connections and controllers are more complicated than if electric braking is not used.

COMBINED ELECTRICAL AND MECHANICAL BRAKES

25. British Thomson-Houston Magnetic Track Brake.—Very effective braking is obtained by combining the ordinary rheostatic-brake connection with a track brake which is applied to the rails magnetically. A track brake of special form is drawn down on the rails with considerable force by magnetic attraction, when current is passed through its exciting coil, the coil being

connected in the ordinary braking circuit, in series with the motors and the starting resistance of the car. The mechanical braking effect due to the magnetic brake is increased as the controller is advanced notch by notch, increasing the current by cutting out the series resistance.

In Fig. 17 is shown the magnetic track brake of the British Thomson-Houston Company. This brake consists of a cast-steel shoe *a* suspended by means of links *b* from a bracket *c* attached to the side of the truck, and is held close to, but clear of, the track by means of the springs *d*. The magnet coil is placed in a recess in the casting *e*, and a steel core extends through

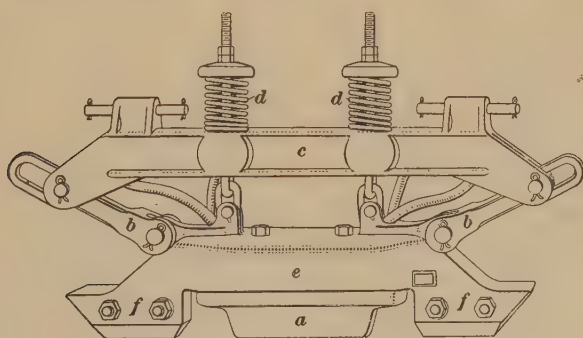


FIG. 17

the coil, providing two magnetic circuits, each of which is completed through the small extensions and shoes *f*, and the section of rail immediately under the shoe. The magnetic attraction exerted between the shoes of each brake and the rail is about 1 ton. The compression of the springs *d*, owing to the lowering of the brake shoes to the track, slightly increases the weight on the wheels instead of reducing it, as is the case with mechanical track brakes. Compared with the rheostatic brake alone, less current is required for the magnetic brake for the same braking effect, consequently there is a reduction in the heating of the motors.

26. Westinghouse Electromagnetic Track Brake.—The efficacy of the magnetic track brake may be greatly increased by utilizing the attraction between the magnetic brake and the rail to

actuate a mechanical brake, applied either to the wheels or to the rails. The former method is used in the Westinghouse brake, and the latter in the Maley brake. The arrangement of the Westinghouse electromagnetic brake is shown in Fig. 18, in which the brake on one side of a car truck is shown as viewed from the opposite side, under the car. The brake gear is placed inside the frame of the car truck. The shoes *a* of the magnetic track brake are drawn down on the rail when the exciting coil *b* is energized by current from the car motors acting as generators. The track shoes and electromagnet are normally held clear of the rail by two springs *c*. The wheel-brake shoes *d*, *d'* are hung

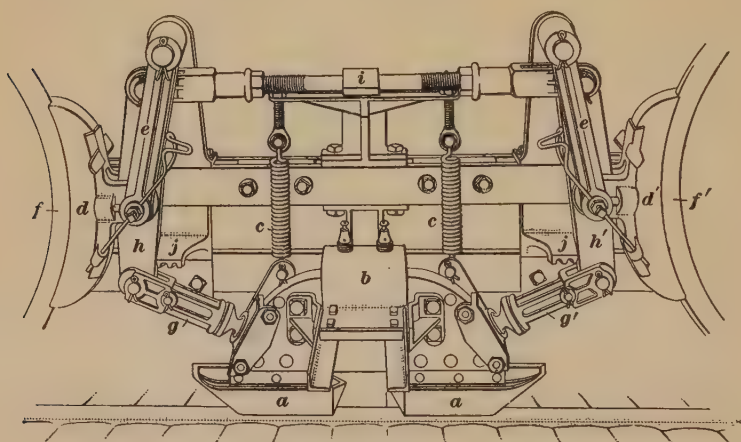


FIG. 18

on links *e*, both the springs *c* and links *e* being hung from brackets fixed to the truck frame. The wheel and track-brake shoes are connected by a link framework so arranged that the act of applying the magnetic brake to the rails also causes, when the car is in motion, the wheel blocks to press against the wheel tires.

27. If the wheels *f*, *f'*, Fig. 18, are rolling from left to right, the track brake, when applied to the rail, drags toward the rear wheel *f*, putting link *g* in compression, and pressing brake block *d* against the wheel *f* through lever *h*, which at first pivots on the joint with rod *i*. Lever *h* now turns about the pivot of brake block *d*, thus putting rod *i* into compression, and moving the

upper end of lever h' toward the forward wheel f' . Without special provision to the contrary, the brake block d' would be drawn away from wheel f' when link g' is put in tension by the track brakes dragging, but the links g and g' are actually extensible, being fitted with springs, and the fixed stops j attached to the truck frame prevent any considerable movement of either wheel-brake block away from the wheel tire. Thus, when rod i is in compression, lever h' pivots first about the brake block d' and then about the fixed stop j , thus braking the forward wheel f' firmly.

28. Maley Electro-Mechanical Track Brake.—When making a quick emergency stop with any wheel brake, whether mechanically or electrically operated, the risk always exists that the wheels may be skidded, due to the too great pressure between the wheels and brake blocks. If the wheels of a car are locked, the retarding effect of the wheels sliding along the rails is less than that obtained when the wheels are running with the brakes applied to them with a force just under that which would cause slipping. Of course, the wheels will skid much more readily if any part of the weight of the car is taken off them due to the application of a mechanical track brake. In order to meet this difficulty, the Maley electro-mechanical brake has been developed, consisting of a magnetic track brake combined with mechanically applied track-brake shoes. The magnetic attraction of the brake increases the adhesion of the wheels on the rails and a three-fold braking effect is obtained, due to the generative action of the car motors in supplying current to the magnetic brake, the friction between the magnetic brakes and the track and between the mechanical brakes and the track.

29. The arrangement of the Maley brake, as applied to the bogie of a double-truck car, is shown in Fig. 19. The excitation of the magnetic-brake shoe a , and therefore its attraction on the rail, and the consequent braking effect obtained, are normally controlled from the car controller, though, in the event of a fault developing in the controller, the track magnet can be excited directly from the trolley wire. The brake rigging is supported on the truck frame at b , and when the magnetic-brake shoe is

applied to the rail, it drags, and tilts the stem which acts as the guide for the shoe *a*. The additional brake shoes *c* and *d* are applied to the rail by means of the levers *e*, which are forced

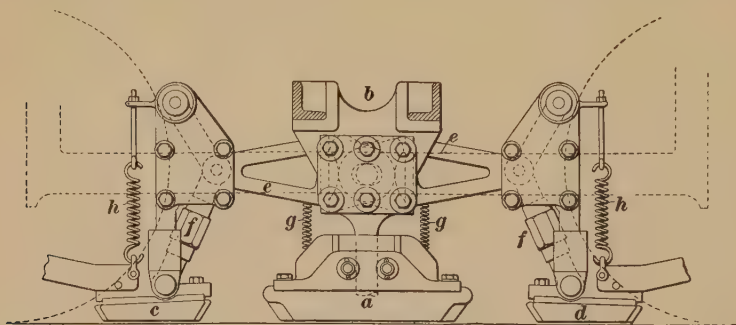


FIG. 19

outwards by the cam between them and thus press downwards on the levers *f*. The springs *g*, *h* serve to hold the brake shoes away from the rail when the brakes are released.

BRAKES FOR ELECTRIC RAILWAYS

ARRANGEMENT OF RIGGING

30. Variations From Tramway and Steam Practice.—Railway braking is confined almost entirely to the use of power-applied wheel brakes. The rails are invariably clean and the adhesion of the wheels good, so that track brakes are not required. Electric brakes have a certain limited use. On single trucks having a rigid wheel base, brake blocks are usually provided on each side of each wheel. On motor trucks, however, there is very often insufficient room for two blocks on each wheel. Brakes hung outside the wheels at both ends of the truck or bogie are the more easily accessible, but in action they tend to tilt the bogie by depressing the front and raising the rear end. On the other hand, brakes hung between the wheels are impossible with some types of motor suspension, on account of lack of space. The general practice in steam-railway work is to connect the

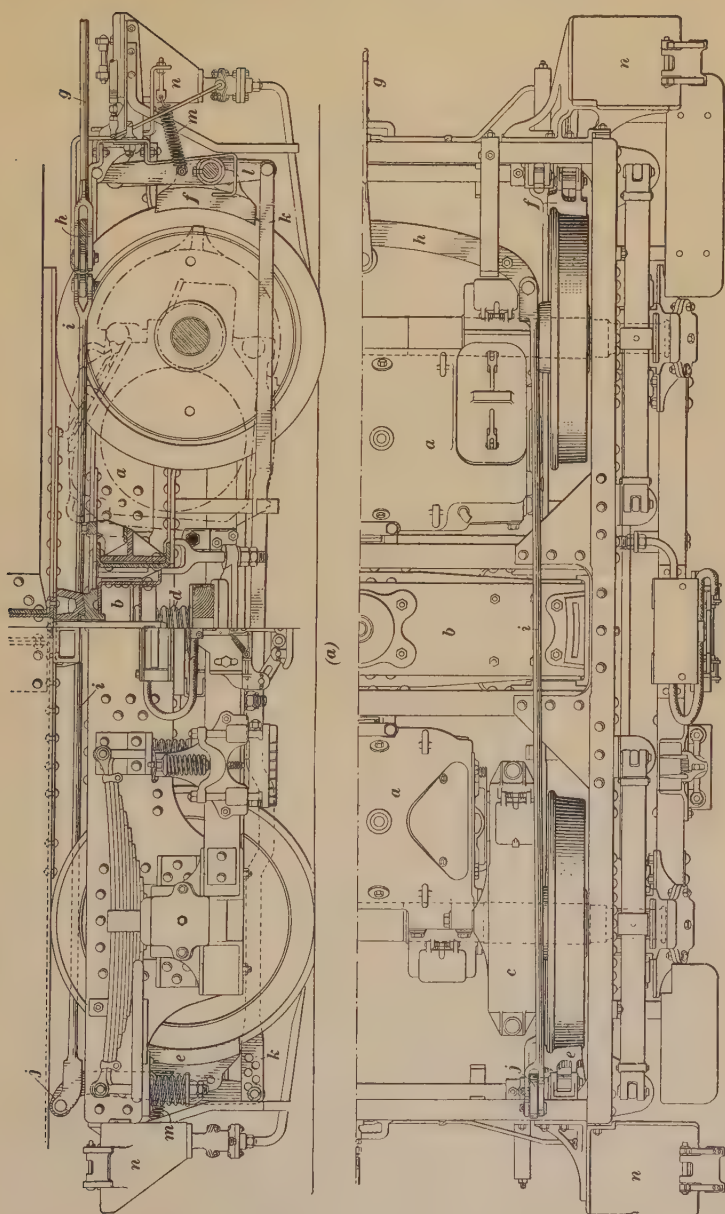
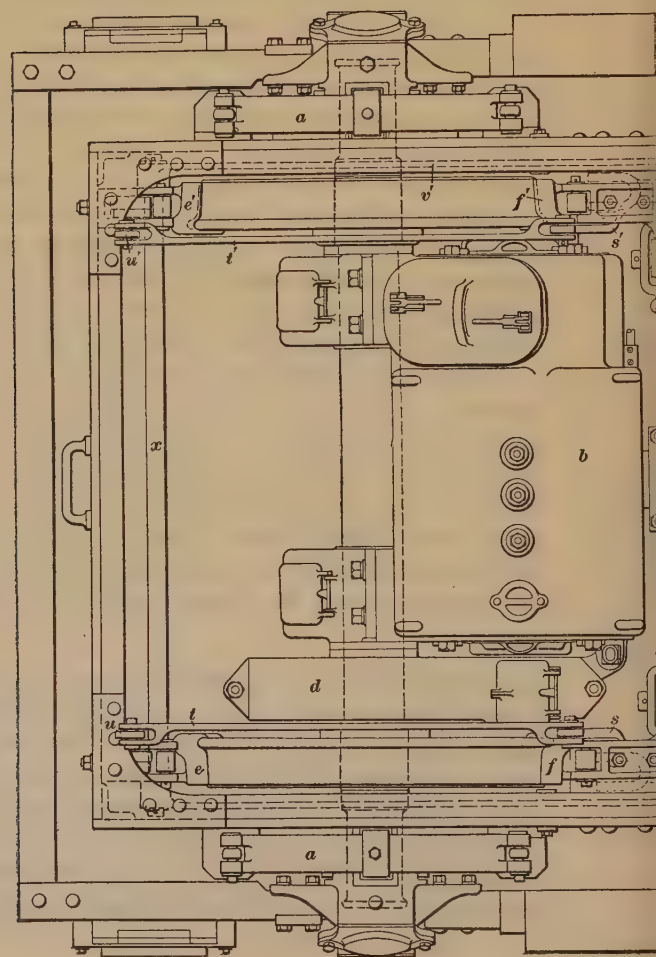
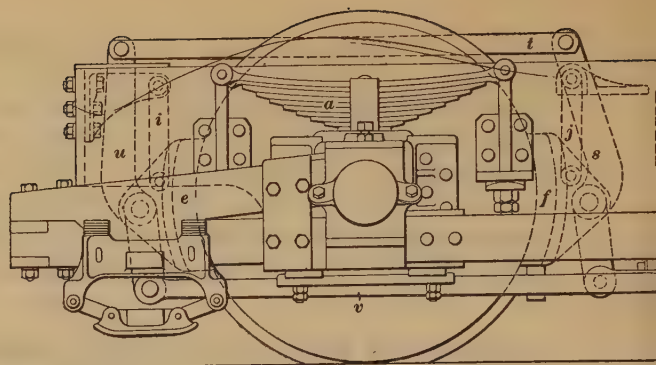


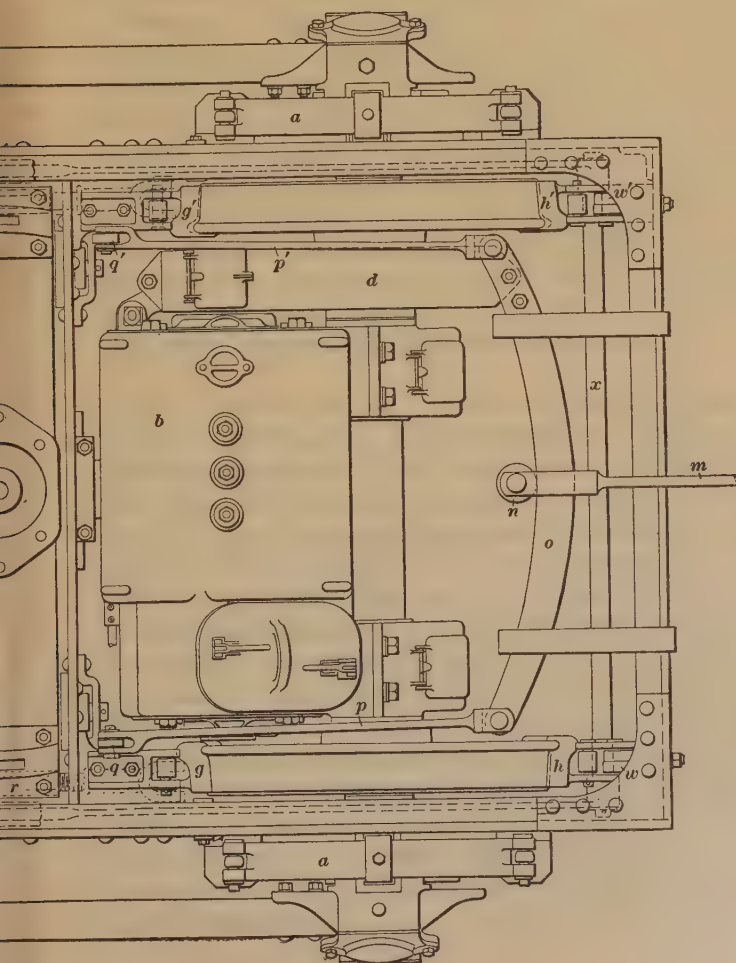
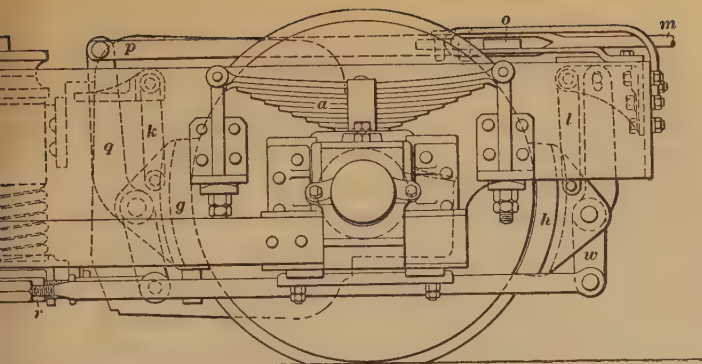
FIG. 20

forward pair of brake blocks directly to one transverse beam, and the rear pair directly to another, the beams being joined through rods and cranks, and operated together by a central lever. As on motor-driven trucks there is no room for such transverse beams in the usual positions, the rigging must be kept at the sides and ends of the trucks, out of the way of the motors.

31. Brake Rigging With One Brake Block Per Wheel.—A brake rigging for a motor bogie with one brake block per wheel, as constructed for the North-Eastern Railway, is shown in Fig. 20 (*a*) and (*b*), which are side-elevation and half-plan views, respectively. The motors *a* are suspended from the axles and the truck bolster *b*, and drive by single reduction gears, one gear-box being shown in plan at *c*. A part of the weight of the motors is supported by the bolster springs *d*. In this case, brake blocks are not provided between the pairs of wheels on each side, but only on the outer sides of the wheels at *e* and *f*. When a pull is applied on rod *g*, it is transmitted by the curved transverse beam *h* to two rods *i*, one on each side, and which extend along the top of the truck to the levers *j*. One lever *j* is pivoted on the brake block *e* and also at the lower end on a tension rod *k*, view (*a*), which connects with the lower end of lever *l*. The lever *l* carries the brake block *f* and is pivoted at its upper end to the truck frame. As soon as the brake block *e* comes in contact with one wheel, rod *k* draws block *f* in contact with the other wheel. Spiral springs *m* are used to draw the brake blocks away from the wheels when the pull on rod *g* is released. Sanding boxes *n* are placed at each end of the bogie frame.

32. Brake Rigging for Brush Bogie.—An arrangement of brake rigging specially adapted to leave the necessary space for two motors, and at the same time to provide every wheel with two brake blocks, is shown in Fig. 21 (*a*) and (*b*), which are elevation and plan views, respectively, of an electric-locomotive truck made by the Brush Electrical Engineering Company for the North-Eastern Railway. The main truck frame is supported on springs *a*. The two motors *b* are carried between





the axles and the bolster *c*; the gear-boxes are shown at *d*. The eight brake blocks *e*, *e'*, *f*, *f'*, *g*, *g'*, *h*, *h'*, view (*b*), are suspended from the frame of the bogie by means of the links *i*, *j*, *k*, *l*, view (*a*). The tension rod *m* ends in a forked head carrying a roller *n*, through which the pull is transmitted to the curved transverse beam *o*. The centre of the curve of this beam coincides with the centre of the bogie, so that the bogie swivels freely without interfering with the action of the rod *m*. Pivoted to the ends of the transverse beam *o* are the brake rods *p*, *p'*, which in their turn are pivoted to the upper ends of the equalizing levers *q*, *q'*. These levers are pivoted at an intermediate point in their length to the brake blocks *g*, *g'*, and at their bottom ends to another pair of rods *r*, *r'*. When a pull is applied to the brake rod *m*, it is transmitted to the top of each equalizing lever *q*, *q'*. These levers first of all turn about their bottom ends which are pin-connected to the rods *r*, *r'*, and press the corresponding brake blocks against the wheels. As soon as the blocks are pressed up, the equalizing levers turn about the intermediate pivots on the brake blocks, and in so doing transmit a longitudinal thrust to the rods *r*, *r'*.

33. The thrust rods *r*, *r'*, Fig. 21 (*a*) and (*b*), apply the brake blocks *f* and *f'* against the second pair of wheels by means of the equalizing levers *s*, *s'*, and then transmit a pull to the rods *t*, *t'*. These rods act through the equalizing levers *u*, *u'* to apply the blocks *e*, *e'* to the wheels and also to transmit a pull to the rods *v*, *v'* which run back the whole length of the bogie to levers *w*, *w'*. The latter are levers pivoted to the rods *v*, *v'*, to the brake blocks *h*, *h'*, and to fixed points on the bogie frame. The pull on the rods *v*, *v'* therefore applies the blocks *h*, *h'* to the wheels. Thus, all the brake blocks on a car go into action when the brake is applied, and with practically the same pressure on the wheels; this tends to secure equal wear in the blocks and a more efficient breaking action generally. Turn-buckles are inserted in the rods *r*, *r'* and *v*, *v'*, so that as the blocks are worn down the slack can be taken up. The ends of the rods *v*, *v'* are connected by transverse bars *x*, so as to tie the whole together.

BRAKING SYSTEMS

COMPRESSED-AIR BRAKES

34. Systems of Air Supply.—There are in general use two systems of air brakes, namely, the *compressed-air system* and the *vacuum system*. In the **compressed-air system** the brakes are operated by means of pistons worked by compressed air, while in the **vacuum system** the brakes are applied by withdrawing air from one side of the brake piston and allowing atmospheric pressure to act on the other side. In order to get sufficient braking force by this means, either the piston area must be large or the piston must act at the end of a long lever arm. In the compressed-air system, the pressure used is usually 60 to 80 pounds per square inch ; this pressure is given by a storage reservoir on the train, a compressor driven by the axle, or a compressor driven by a small electric motor.

35. Storage System.—If air for braking is supplied from a storage reservoir on the train, the reservoir must be large enough to supply the brake cylinders during the entire run between recharging stations, and there should be ample reserve capacity in the reservoirs to allow for emergencies. The pressure in the storage reservoir is usually much higher than the pressure applied to the brake cylinders, a reducing valve being used to keep the braking pressure at the proper value. The system has the advantage of the braking equipment on the train being very simple. The pumping or compressor plant at the recharging stations also works under most favourable conditions, being always under full load and having no restrictions as to space available for equipment. The disadvantages are that each application of the brakes reduces the pressure of the air in the reservoir, for this, together with leakage, may render the brakes inoperative.

36. Axle-Driven Compressor System.—When the axle speed of a train is not greater than 150 revolutions per minute, compressed air may be obtained by means of a compressor driven directly from the car axle. This method of operating the

compressor is open to the objections that the compressor is running whenever the train is in motion and thus does unnecessary work when the reservoir is charged, while if the stops are frequent and the grades heavy the compressor may not be able to supply the amount of air necessary to operate the brakes efficiently. If a train has been standing for some time, the air stored in the reservoirs may have leaked away and the brakes will be inoperative until the train has travelled some distance and the compressors have again recharged the storage tanks.

37. Motor-Driven Compressor System.—The system of supplying the compressed air by separate motor-driven compressors is the one most commonly used. The reservoir pressure is maintained within the desired limits by an automatic controller, which starts the motor whenever the pressure falls below a certain limit, and stops the motor when the pressure reaches a given maximum. This system offers all the advantages of the axle-driven compressor system by making the air supply for each coach independent of the others. The compressor runs only when necessary, and will charge the reservoirs whether the train is running or standing so long as there is a supply of electrical energy. The disadvantages are that the equipment is somewhat complicated due to the motor connections and automatic controller.

38. Train Pipes.—The pneumatic-brake equipment of electric railways differs little from that used on steam railways. The brakes on each coach are operated by air from an auxiliary reservoir which the coach carries. The brakes are controlled by means of special balanced valves, called *triple valves*, which may be operated by the motorman's or driver's valve by reducing the pressure in a pipe running the full length of the train and called a **train pipe**. Where a train includes more than one motor coach, each coach necessarily contains a complete brake equipment, and means must be provided whereby, in case of necessity, the compressor on one motor coach can supply compressed air to the reservoirs of the other motor coaches. For this purpose an additional pipe, called a **reservoir pipe**, is provided, which connects the main reservoirs on the motor cars, so that, in the

event of one compressor breaking down, its reservoir is supplied from the other compressors through this second pipe.

39. Typical Equipment.—A complete air-brake equipment for a single coach is represented in Fig. 22. At the bottom of the illustration is the main reservoir *R m*, which is connected through the reservoir pipe to the reservoirs on the other motor coaches. The main reservoir is supplied with compressed air through the check-valve 28, which is an ordinary flap valve, from the compressor, which is driven by the pump motor. Current for driving the pump or compressor motor passes from the positive main through the pump switch and fuse and pump-governor switch to the armature *A* and fields *F* of the motor and then to ground or earth. The function of the pump governor is to cut off current from the compressor motor when the reservoir pressure has reached a desired amount, and to start the motor again when the pressure falls. This regulation is effected by the governor piston 30, which works in a cylinder 29 against a spring 31. At the end of the piston rod is pivoted a lever, which moves about a fixed pivot 33, its other arm consisting of an insulated switch arm 32 by means of which connection can be made between the contacts 34 and 35. When the reservoir pressure reaches the normal value, the governor piston 30 is moved against the action of the spring 31 and opens the switch 32, 34, 35; when the pressure falls, the piston is moved inwards by the spring and closes the switch, thus starting the compressor motor. Insulating couplings are provided in the pipe connections between the main reservoir and the pump governor and the compressor, respectively. These couplings insulate the electrical apparatus from the earthed portions of the brake equipment, and they reduce the P.D. between the windings and the body of the apparatus, thus reducing the liability of breakdown in the insulation.

40. Control Valves.—At the top of Fig. 22 is shown the train pipe, which is connected to the chamber *L'* of the triple valve, chamber *R* of which is connected with the auxiliary reservoir *R a*, while chamber *B* is connected with the brake cylinder. The piston of the brake cylinder is connected with the brake rigging, and when the piston moves out the brakes are applied

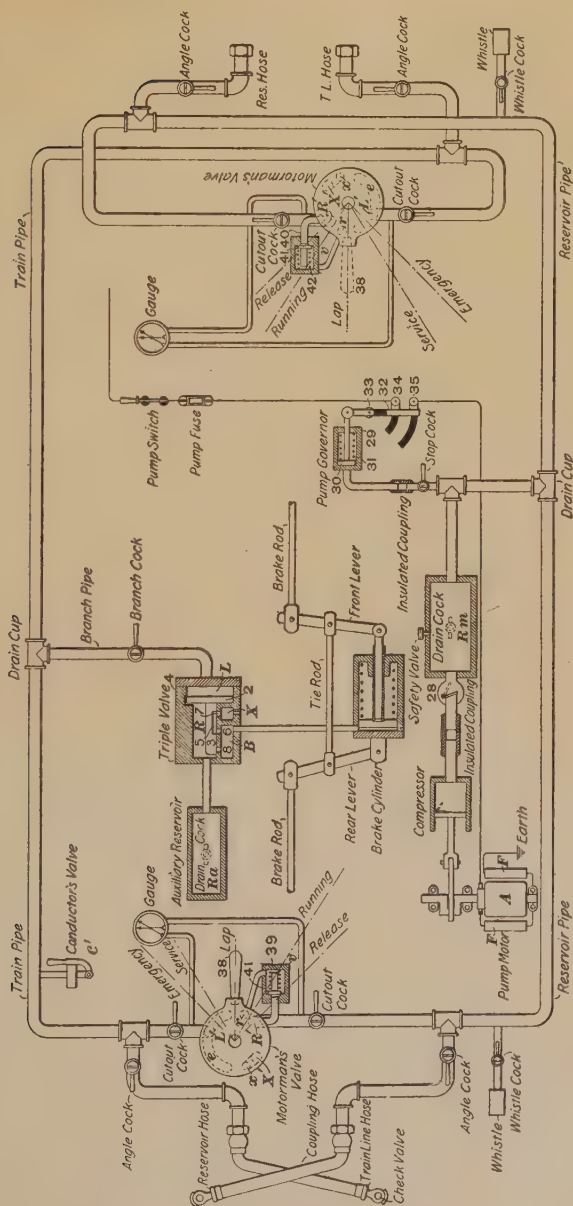


FIG. 22

in the usual way by means of the brake rods. The supply of air to the train pipe is governed by the motorman's valves, which are shown at the right and left of the illustration. In the motorman's valve, exhaust ports X, x in the valve seat connect together and open directly to the atmosphere; ports R', r do not connect to each other except through feed-valve 39, which makes connection between the train pipe and reservoir pipe under certain conditions. Port R' opens to the reservoir pipe and L' to the train pipe. By means of the curved cavity e in the rotary part of the valve, any desired connection between the ports can be established.

41. Lap Position of Valve.—In Fig. 22, the handle 38 of the motorman's valve is shown in the **lap position**, in which there is no connection between the various valve ports. This is the only position in which the handle can be put on or removed. Lap position is used when it is desired to hold temporarily to the condition which has been established in the braking system. For example, if it is desired to hold the train stationary on a gradient, the train is stopped and the valve handle moved to lap position, in which no motion of air through the braking system is possible.

42. Service Position of Valve.—When the handle 38, Fig. 22, of the motorman's valve is moved to the **service position**, cavity e connects the train pipe to atmosphere through port x . The pressure in the auxiliary reservoir moves the piston 2 and slide valve 3 of the triple valve to the right, thus establishing connection between the brake cylinder and the auxiliary reservoir through port 8 and closing the port 6, which normally connects to the exhaust chamber X through cavity 5 and port 7. By this means, the brake piston is moved out against the spring and operates the brakes in the usual way. In the emergency position, the train pipe is connected to the atmosphere through both ports x and X , and therefore the brakes are operated more rapidly than in the service position. A valve c' is fitted to the train pipe and placed where it can be easily operated by the conductor in case of emergency. Any accidental injury to the train pipe applies the brakes by connecting the train pipe to the atmosphere.

43. Running Position of Valve.—When the motorman's valve is in the running position, cavity *e*, Fig. 22, is connected to port *r*. If the difference of pressure between the reservoir pipe and train pipe exceeds 20 pounds per square inch, the feed-valve piston 41 will be lifted against the action of spring 42 and air will pass from reservoir pipe to train pipe through valve 39 until the difference of pressure falls and the combined action of train-pipe pressure and the pressure of spring 42 closes the feed-valve. On steam trains, the governor maintains the pressure in the main reservoir at 90 pounds per square inch, and the feed-valves are set to keep the pressure in the train line at 70 pounds per square inch. On electric trains using electric governors that do not operate until a certain minimum or maximum pressure is attained, the excess pressure, that is, the excess of the pressure in the reservoir pipe over that in the train pipe, is necessarily variable.

44. Release Position of Valve.—In the release position of the motorman's valve, cavity *e*, Fig. 22, covers ports *R'*, *r*, and *L'*, thus admitting high-pressure air from the main reservoir to the train pipe. In this way, the pressure in chamber *L* of the triple valve is raised above that in the auxiliary reservoir *R a* by an amount equal to the excess pressure, and therefore the triple-valve piston 2 moves to the left, closing port 8, and connecting the brake cylinder with the atmosphere through the ports 6 and 7 and exhaust chamber *X*. The brake piston moves to the left under the action of the spring and releases the brakes. In this position of the triple valve, the auxiliary reservoir is supplied with air from the train pipe through the feed-groove 4.

VACUUM BRAKES

45. Arrangement of Exhausters.—On steam railways which use vacuum brakes, the locomotive is generally provided with two steam-actuated air exhausters, termed *ejectors*; a small one, which is working continuously, to maintain the vacuum against leakage, and a large one to restore the vacuum in the train pipe and brake cylinders for the release of the brakes.

The restoration of the vacuum which releases the brakes must take place quickly, and therefore the large ejector must have considerable capacity. As an equivalent of this equipment on electric railways there are various alternatives. Where all the cars are fitted up on the same system, two train pipes may be used, one for applying the brakes, and the other for releasing them by equalizing the pressure above and below the brake piston. In some cases, however, trains may contain coaches provided with only one train pipe; two motor exhausters may then be provided on each motor car, one being driven at half-speed to maintain the vacuum. For releasing the brakes, both exhausters are run at full speed, and the vacuum is restored in a very short time.

A single exhauster running normally at quarter-speed, but at full speed when releasing the brakes, may be used instead of the arrangement previously described. This has the advantage of simplicity, but in the case of a single car there is no provision against the breakdown of the exhauster or motor. By duplicating the exhausters, the brakes can always be operated, even though only one exhauster can be run, although it will take longer to release the brakes after application.

46. Equipment of an Electric Locomotive.—A diagram of the arrangement of the exhauster, brake cylinder, and piping, suitable for an electric locomotive, is given in Fig. 23. The exhauster motor *a* drives the exhauster *b*, through a flexible coupling, and is controlled by the switch *c*. According to the position of the switch handle on the contacts 1, 2, 3, the motor is at rest, or driving the exhauster at one-quarter speed, or full speed, as the case may be. The low speed is secured by connecting a resistance *d* in series with the motor armature when the switch *c* is on the middle contact 2. The exhauster can be put into connection with a vacuum chamber *e* carried on the locomotive and with the train pipe *f* by means of the driver's valve *g*, which is mounted in the cab conveniently near the electrical controller. The air withdrawn by the exhauster is returned to the atmosphere through the exhaust pipe *h*, which is taken below the floor of the cab.

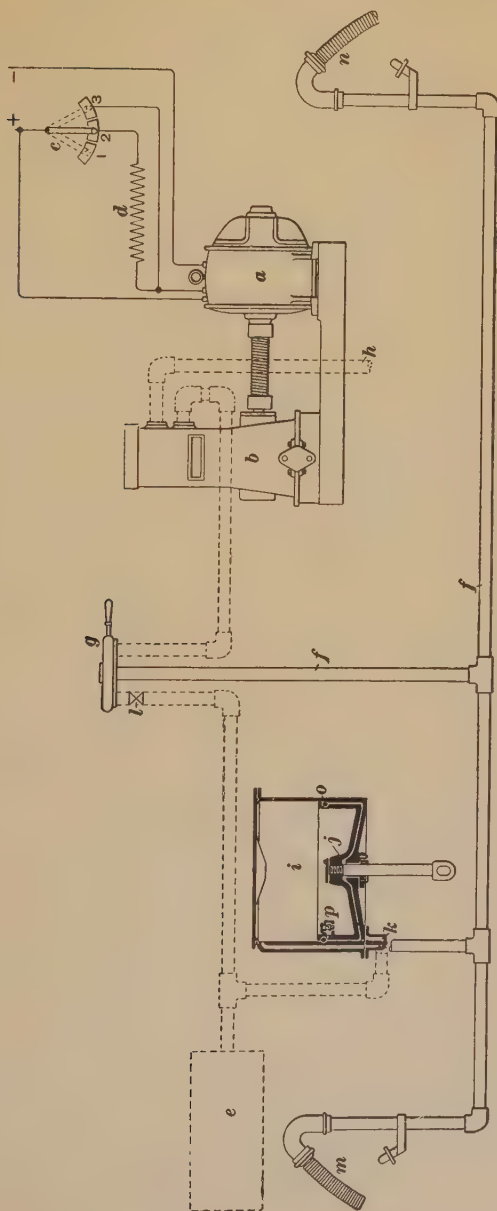


FIG. 23

47. Under ordinary running conditions the exhauster is driven at low speed and maintains a vacuum both in the vacuum chamber e and the train pipe f , with both of which it is connected through the driver's valve. The vacuum chamber e is in communication with the space i in the brake cylinder above the piston j , and the train pipe is in communication with the port k leading to the lower side of the piston. The piston therefore remains in equilibrium, with the brakes off. To apply the brakes, air is admitted to the train pipe through the driver's valve, but the vacuum is maintained in the chamber e and above the piston j . The air pressure in the train pipe then lifts the piston j and applies the brakes. To release the brakes before starting the train, the exhauster is run up to full speed and is put into communication with the train pipe through the driver's valve. As the vacuum is attained in the space below the brake piston j , and the pressure above and below the piston is equalized, the piston falls and the brakes are released from the wheels by gravity. When the locomotive is uncoupled from the train and there is air in the train pipe, air may be admitted to the vacuum chamber e and the pressure above and below the brake piston equalized by means of the release valve l . Couplings are provided at m and n for connecting the pipe f to the train pipe which runs through the coaches of the train.

48. The piston j of the brake cylinder is packed with a rubber ring o , known as a rolling ring, because it rolls up and down the cylinder wall with the movement of the piston; this ring effectually prevents any appreciable leakage from one side of the piston to the other. The ball valve p is provided on the piston so that both the top and bottom ends of the cylinder may be exhausted through the train pipe to the same degree of exhaustion when the brakes are released and the piston is in the lowest position, independently of the existing connection from the brake cylinder to the vacuum chamber e . When air is admitted into the train pipe to apply the brake, it holds the ball valve firmly on its seat, so that air cannot pass into the upper part of the cylinder; this preserves above the piston the vacuum which is necessary in order that the brake may act.

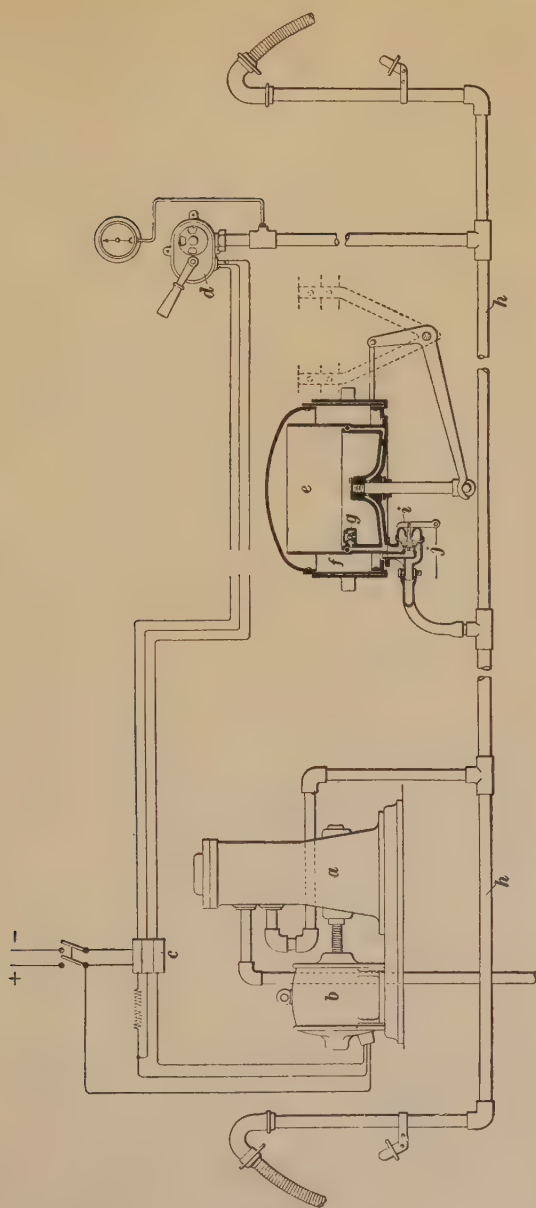


FIG. 24

49. Arrangement of Vacuum Brake on Midland Railway.

The brake equipment of the coaches on the electrified Heysham line of the Midland Railway has some special features. The general arrangement of the brake control is shown diagrammatically in Fig. 24. The exhaustor *a* is driven by a motor *b*, which is controlled by a contactor group *c* actuated from the driver's combined air valve and switch *d*. No separate vacuum chamber is provided; the brake cylinder *e* combines the functions of the vacuum chamber and the separate brake cylinder shown in Fig. 23. The brake cylinder proper, Fig. 24, is enclosed in an outer vacuum chamber *f*, in which a vacuum is continuously maintained, the degree of exhaustion being kept up by the withdrawal of air through the ball valve *g*, when the train pipe *h* is exhausted and the brakes are released. Release of the brakes when the exhaustor is at rest is obtained when the valve *i* is opened by pulling the release cord *j*, thus admitting air to both sides of the brake piston.

50. Combined Driver's Valve and Switch.—The general arrangement of the combined driver's brake valve is shown in Fig. 25 (*a*) and (*b*). The train pipe is connected by means of a union nut to the chamber *a*, view (*b*), through the opening *b*, view (*a*). The front of this chamber is a flat surface *c*, containing openings or ports; the front of the cover, or valve *d*, is perforated to correspond to the openings in the face of the chamber *a*. The valve is so arranged that the latter openings are normally covered. If the valve is turned about its centre, the ports are uncovered to a certain extent depending on the movement of the valve. Air is admitted through the perforations and the ports to the train pipe, and the brakes are applied. The movement of the valve is effected by means of the driver's brake-valve handle *e*, on the switch *f*. This switch consists of a disc *g*, carrying a pair of carbon blocks *h* by means of which connection is made between the two contact segments *j* and *k* or between segment *j* and the block *l*. The disc is geared with the valve *d* by means of the roller *m* working in slot *n*.

51. Positions of Control Valve.—There are three positions of the combined driver's valve. In the first position, the air

ports are closed and segments *j* and *k*, Fig. 25, are connected. This is the normal **running position**, vacuum being maintained in the train pipe by the vacuum pump running slowly, thus keeping the brakes released. In the **release**, or **off**, position, the air ports are closed and segments *j* and *l* are connected, so that the contactor governing the full speed of the pump motor is excited. The valve is put into this position for restoring the

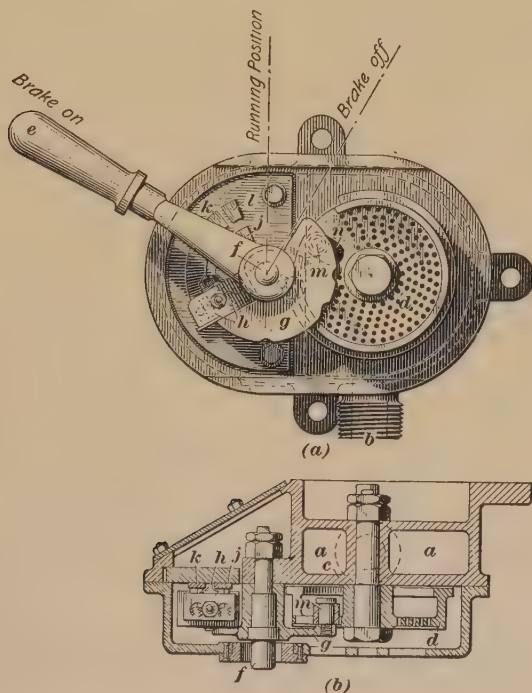


FIG. 25

vacuum, that is, for releasing the brakes. In the **on-position**, the ports are open and segments *j* and *k* are connected. In this position the pump is running at low speed and air is admitted, as desired, to the train pipe, thus causing the brakes to be applied.

52. Quick-Release Vacuum Brakes.—A quick-schedule train speed cannot be maintained unless the brakes are released

within a few seconds after the train comes to rest in the station. Therefore, trains which have to make short quick runs between stations must have provision for the quick release of the brakes. On the Liverpool-Southport line, all the carriages have special vacuum reservoirs and release valves, so that the pressures above and below the brake piston can be quickly equalized. The special release valves connect the train line with the vacuum reservoir, thus at once reducing the pressure sufficiently to release the brakes and allow the train to start.

TRAMWAY MOTORS AND CONTROLLERS

TRAMWAY MOTORS

SELECTION, RATING, AND LUBRICATION OF MOTORS

DETERMINATION OF TYPE, SIZE, AND RATING

1. **General Features of Traction Motors.**—Traction motors must be substantially constructed because the duty imposed on them is very different to, and usually much heavier than, the duty of stationary motors of similar size. Their design, also, is limited by the fact that they must be placed beneath the floor of the tramcar they drive and between the car wheels. They must be dust-proof and waterproof because they will have to run in all kinds of weather, and must be so arranged as to be readily suspended from the car frame and axle. The frame of a tramway motor is always of cast steel in order to secure lightness, and the pole pieces, instead of being cast with the frame, are generally built up of sheet-iron laminations and are bolted to the frame, as shown in Fig. 1. This laminated-pole construction reduces heating in the pole pieces and also tends to minimize sparking at the commutator. The

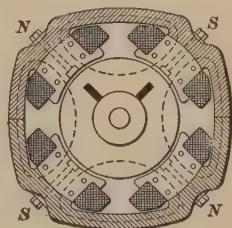


FIG. 1

armatures of traction motors are always of the slotted type, with former-wound coils placed in the slots on the core. In the earlier types of armature, a large number of slots were used, generally from 87 to 105, the reason being that, if the slots were made wide, they caused the magnetic density in the pole pieces to vary to such an extent as to cause hysteresis and eddy-current losses in the solid poles, which were consequently overheated. By laminating the poles, it has been found possible to reduce the number of slots to about one-third the number formerly used, thus making them very much larger, cheapening the cost of production, and making the motor operate better generally. The field coils should be connected so as to give alternately north and south poles, as indicated by the letters *N* and *S*.

2. Comparison of Types of Motors.—Nearly all the motors used on tramways are of the direct-current series-wound type ; alternating current has not been used practically for tramway work, apart from the transmission between the power station and substations. For tramway service, a motor must have a strong starting effort and must supply an increasing torque with decreasing speed. Shunt-wound motors run at a nearly constant speed regardless of load, and a car equipped with them will ascend inclines at about the same speed that it will run on the level, and will then take an excessive current from the trolley wire, if special controlling devices are not used. A series-wound motor, on the contrary, will decrease its speed automatically when the load is increased. Variable speed is essential for traction working, and the shunt-wound motor is a constant-speed machine ; hence, for this class of work, it has never been widely used. The series motor can be made to exert a very strong starting effort ; all the current that flows through the armature also flows through the field coils, and a very strong field is thus obtained at starting. With a shunt motor, the amount of field excitation is fixed by the line voltage and the resistance of the shunt winding ; consequently, the field cannot be strengthened to any great extent in order to obtain an especially strong torque. Another incidental advantage of the series motor is that the field coils consist of a comparatively small number of turns of

coarse wire, and are much cheaper to wind and more substantial to withstand service conditions than fine-wire shunt coils.

3. Shunt motors have one advantage over series motors, however; they may be used for **regenerative working**, that is, they can be used to generate and return power to the line automatically when descending hills and when stopping. Besides being economical in current, this regenerating action assists in braking the car when descending hills and it is not possible for cars fitted with this control system to run away. The various accidents which have occurred owing to tramcars getting beyond control on steep hills make the braking property of the shunt motor with regenerative control a most valuable one.

4. **Armature Windings.**—The armatures of traction motors are practically always wound with a drum winding of the series or wave type, which has only two circuits, whatever the number of poles of the machine. The two-circuit or wave winding has many advantages for traction motor work, not the least of which is that it requires only two brushes. If four brushes had to be used, as would be necessary with a multiple-circuit or lap winding, access to the lower brushes would be difficult. Another advantage of the two-circuit winding is that uneven centring of the armature due to wear in the bearings or other causes does not produce unequal distribution of current in the armature and sparking at the brushes, such as would be the case with a lap-wound armature.

5. **Choice of Size.**—The selection of the proper size of motor to be used for a given car service is a subject that must be carefully considered. If the motors provided are not powerful enough, the cars will not be able to maintain the required schedule time; or, if forced to do so, there will be a large number of breakdowns and the cost of repairs will be heavy, to say nothing of the loss due to the dislocation of the service. On the other hand, if motors much larger than required are installed, an unnecessary outlay of capital is entailed and the system is burdened with an expense that might have been avoided. Besides, unnecessarily large and heavy motors involve waste of

power, because of the extra weight that must be propelled and also because of the greater iron losses in the larger motor. Finally, excessive dead weight on the car causes an unnecessary pounding on the rail joints and consequent deterioration of the track. Usually, in the British Isles, the size of motor lies between 25 horsepower and 35 horsepower, two motors being used per car. In order to secure the best results, the selection of the motor can be made only after a careful consideration of all local conditions affecting the power necessary to propel the cars ; and it is always better to have the motors a little too large than too small.

6. Rating of Traction Motors.—As a tramway motor is always worked on a varying load, it is difficult to rate the output of the motor so that the practical load conditions are imitated exactly. The load that a motor can carry is limited by the heating effect, and it has become customary to rate traction motors according to the output, in brake horsepower, that they will deliver continuously for a period of 1 hour with a temperature rise not exceeding 75°C. above surrounding air at 25°C. For example, according to this rating, a 35-horsepower tramway motor is one that will deliver 35 horsepower for 1 hour with a rise in temperature of 75°C. , providing the temperature of the surrounding air is not more than 25°C. This method of rating is not wholly satisfactory, and it does not follow that 35 horsepower in this case is the best rating to put on the motor when driving a tramcar, but the rating is useful in giving a comparative idea as to the capacities of motors, and the performance, as regards sparking and general behaviour, of the commutator and brushes.

7. Average and Effective Values of Current.—The heating of a traction motor is due to the copper or C^2R loss in the windings and the iron loss in the armature. The copper losses depend on the current, and this is continually changing in amount. The current is large at starting, but rapidly falls off as speed is attained, while at times the car may coast along without taking any current. The heating effect of the current is proportional to the square of the current at any given instant, and the heating effect of the variable current will be the same as that of a steady current having a value equal to the square root of the mean

square of the various values of the variable current. If, then, a motor is to operate without overheating, this **square-root-of-mean-square, or effective, value** of the current must not exceed that which the motor could carry continuously. It should be noted that the effective current is not the same as the average current taken by the car, nor the same as the current that can be carried at the 1-hour rating. To find the average power, in kilowatts, in any particular case, the average value of the current may be estimated by dividing the number of kilowatt-hours per car, taken during any given interval of time, by the time, in hours. The average watts can be determined by multiplying the average kilowatts by 1,000. If this value is divided by the average line voltage, the quotient will be the average value of the current, in amperes. The effective value of the current may be assumed to be 1.35 times the average value for ordinary conditions of tramway working.

LUBRICATION OF MOTORS

8. **Lubricants.**—The question of proper lubrication for tramway motors is an important one. Insufficient lubrication not only causes a waste of power, but may lead to serious damage if the bearings are allowed to wear rapidly down so as to let the armature rub on the pole pieces. Either grease or oil may be used for lubricating. A drawback of grease is that it does not feed down until it is melted by the bearing becoming warm, while, with oil, it is difficult to limit the flow, and any excess of oil fed into the bearings may find its way into the motor case, where it causes a great deal of harm to the insulation of the field coils and armatures. Perhaps the most satisfactory method is to use grease for the armature bearings and oil for the axle bearings. As the motor case is always slightly warm when running, the feeding of the grease is helped, while the axle bearings are slow-running and cold, and are situated where any excess of oil cannot do damage.

9. **Methods of Lubrication.**—Both the armature and axle bearings of most tramway motors are provided with some kind

of absorbent wick or pad which carries the oil or grease to the journal and distributes it over the bearing surface. The oil or grease may be placed above the journal to be lubricated or in a reservoir beneath. If the first arrangement is used, the renewal of the wick or pad when necessary is a very easy matter, but there is a tendency for too much lubricant to reach the journal immediately after oiling. The method of using an oil reservoir below the shaft and using a wick to carry the oil to the bearing surface has given very satisfactory results, as the supply of oil is nearly constant. In some cases, both the wick and pad methods of lubrication are used. Some types of the Dick-Kerr tramway motors have ring-oiled armature bearings such as are used on stationary motors. The axle bearings are lubricated in all cases by means of pads or wicks.

GEARS AND MOTOR CHARACTERISTICS

GEAR RATIOS

10. Speed-Reducing Gear.—It is not practicable nor economical to drive electric tramway cars by means of motors having their armatures mounted directly on the axles, because the low-speed motors then required will be too large and too heavy. The motors are therefore always geared to the axle. A pinion on the armature shaft engages with a spur wheel keyed to the axle, and both pinion and wheel are enclosed by a gear-case that contains a quantity of heavy oil. The reduction in speed that will be obtained from the motor shaft to the axle depends on the ratio of the number of teeth in the spur wheel and pinion; the larger the pinion gearing into a given size of spur wheel, the smaller will be the reduction of speed.

11. The **gear ratio** of any combination is the ratio of the number of teeth in the spur wheel to the number in the pinion. The number of teeth in the pinion is always considerably smaller than the number in the spur wheel. If, then, a motor has 14 teeth in the pinion and 68 in the spur wheel, the gear ratio

is $\frac{68}{14} = 4.86$, and the motor armature must rotate 4.86 revolu-

tions for each revolution of the car axle; that is, the motor armature must run 4.86 times as fast as the axle. Table I

TABLE I
SPEEDS OF CAR AXLE CORRESPONDING TO VARIOUS
SPEEDS OF CAR

Speed of Car		Speed of Car Axles, in Revolutions Per Minute						
Miles Per Hour	Feet Per Minute	30-Inch Wheels	31-Inch Wheels	32-Inch Wheels	33-Inch Wheels	34-Inch Wheels	35-Inch Wheels	36-Inch Wheels
6	528	67.2	65.0	63.0	61.1	59.3	57.6	56.1
8	704	89.6	86.7	84.0	81.5	79.1	76.8	74.7
10	880	112.0	108.4	105.0	101.8	98.9	96.1	93.4
12	1,056	134.4	130.0	126.0	122.2	118.6	115.2	112.1
14	1,232	156.9	151.7	147.0	142.6	138.4	134.5	130.7
16	1,408	179.2	173.4	168.0	163.0	158.2	153.6	149.4
18	1,584	201.7	195.1	189.0	183.4	178.0	172.9	168.1
20	1,760	224.0	216.8	210.0	203.7	197.8	192.1	186.8
22	1,936	246.5	238.4	231.0	224.1	217.5	211.3	205.5
24	2,112	268.8	260.0	252.0	244.4	237.3	230.4	224.2
26	2,288	291.3	281.8	273.0	264.8	257.1	249.7	242.9
28	2,464	313.8	303.4	294.0	285.2	276.8	268.9	261.4
30	2,640	336.1	325.1	315.0	305.6	296.6	288.2	280.2
32	2,816	358.4	346.8	336.0	326.0	316.4	307.4	298.8
34	2,992	380.9	368.4	357.0	346.3	336.2	326.6	317.6
36	3,168	403.4	390.2	378.0	366.7	356.0	345.8	336.2
38	3,344	425.8	411.8	399.0	387.1	375.7	365.0	354.9
40	3,520	448.0	433.6	420.0	407.4	395.6	384.2	373.6
42	3,696	470.6	455.2	441.0	427.8	415.3	403.5	392.3
44	3,872	493.0	476.8	462.0	448.1	435.1	422.6	411.0
46	4,048	515.4	498.5	483.0	468.5	454.8	441.9	429.7
48	4,224	537.6	520.0	504.0	488.8	474.6	461.1	448.4
50	4,400	560.2	541.8	525.0	509.2	494.4	480.3	467.0

gives the speed of car axles, in revolutions per minute, for different car speeds and diameters of wheels. In any given case, the speed of the motor armature is obtained by multiplying the speed of the axle, in revolutions per minute, as given in Table I, by the gear ratio.

EXAMPLE.—A car mounted on 33-inch wheels runs at a speed of 20 miles per hour; how many revolutions per minute do the motor armatures make if there are 65 teeth in the spur wheel on the axle and 15 teeth in the motor pinion?

SOLUTION.—The speed of the car axle, Table I, for 33-in. wheels and a speed of 20 mi. per hr., is 203·7 R.P.M. The gear has 65 teeth and the pinion 15; hence, the gear ratio is $\frac{65}{15} = 4\cdot33$. The speed of the armature is therefore $203\cdot7 \times 4\cdot33 = 882$ R.P.M., approximately. Ans.

12. Gears Used in Practice.—Various gear ratios are used in practice, depending on the size of the motor and the speed at which the cars must run. Usually, the spur wheel on the axle has from 4 to 5 times as many teeth as the pinion, although smaller gear ratios are sometimes used if the motors are of large size and the speed of the car is high. The gears have involute teeth and, as a rule, a diametral pitch of 3; that is, there are three teeth on the wheel and pinion for each inch diameter of their respective pitch circles. For very heavy traction work, gears having a diametral pitch of $2\frac{1}{2}$ are sometimes used. The distance between gear centres, that is, between the shaft and axle centres, is fixed for a given motor; hence, the sum of the circumferences of the two pitch circles is also fixed. Any increase in the number of teeth in one gear must therefore be accompanied by a corresponding decrease in the other, as the sum of the number of teeth in the two gears must be constant. For example, if a 15-tooth motor pinion gears with a 65-tooth spur wheel on the car axle and it is to be replaced by a 14-tooth pinion, a 66-tooth spur wheel must be used. Whatever combination of gear and pinion is used, the distance between centres being fixed, the total number of teeth in spur wheel and pinion must be 80, otherwise the gears will not mesh properly.

CHARACTERISTIC CURVES

13. In determining the suitability of a motor for a given class of service, it is necessary to have information showing the performance of the motor. This is obtained from tests made by the manufacturers, and is usually given in the form

of curves, known as the characteristic curves or performance curves of the machine; these show the relation between the current, speed, tractive effort, brake horsepower, and heating effect. A set of the performance curves for a 500-volt 38-horsepower motor is given in Fig. 2.

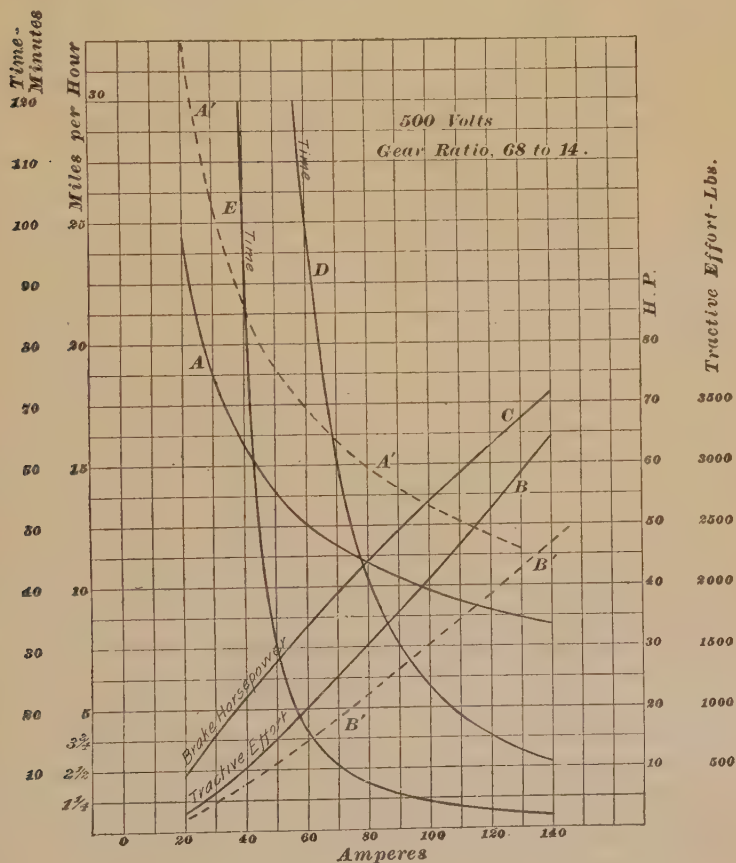


FIG. 2

14. Speed Characteristic.—The curves, Fig. 2, are drawn for a constant terminal P.D. of 500 volts, this being the normal voltage at which the motor is intended to operate. As the load and current of a series motor increase, the speed decreases,

because of the increase in field strength ; the variation of the current and of the speed of the car are shown by the curve *A*. For instance, when the car is running at 20 miles per hour, the motor current is 27 amperes ; if the speed is 10 miles per hour, the current is 96 amperes. The speed of the car corresponding to any given current depends on the gear ratio and the diameter of the wheels, and both of these must be stated in connection with the characteristic curves for any given motor. In this case there are 14 teeth in the motor pinion and 68 in the spur wheel, and the car wheels are 33 inches in diameter. A curve showing the relation between armature speed in revolutions per minute and current would have the same general shape as *A*.

15. Effect of Increase in Voltage.—An increase in the voltage applied to the terminals of a series motor causes the speed to increase in almost direct proportion. For example, reading from curve *A*, Fig. 2, the speed corresponding to 60 amperes is 12·5 miles per hour ; if the pressure were increased from 500 volts to 600 volts, the speed corresponding to the same current would be, approximately, $12\cdot5 \times \frac{600}{500} = 15$ miles per hour.

16. Tractive Effort Curve.—Curve *B*, Fig. 2, shows the relation between the current and tractive effort of a single motor, and gives the total tractive force exerted on the rails by the two wheels on which the motor is mounted. Thus, for a current of 50 amperes, the total tractive effort at the rail head is 750 pounds, or 375 pounds at each driving wheel. The torque of a series motor increases rapidly with the current ; since the tractive effort is proportional to the torque of the motor, curve *B* has the same general shape as a curve showing the relation between motor torque and current.

17. Heating Characteristics.—Curve *D*, Fig. 2, shows the time taken for the temperature of the motor to rise 75° C., or from 25° C. to 100° C., when carrying various currents. Thus, reading from the curve, a load of 70 amperes can be carried for 60 minutes if the motor is started at a temperature of 25°,

so that on the 1-hour rating, with a temperature rise of 75°C. , this motor will develop a rated output, reading from the horsepower curve *C*, of about 38 brake horsepower. However, under ordinary running conditions, the motor is much hotter than 25°C. to begin with, if it has been working under service conditions before the test commences, and the further time during which it can carry a given steady current without rising in temperature above 100°C. will be much less than is indicated by curve *D*. The time taken for the temperature of the motor to increase to 100°C. , after the motor has attained a temperature of 80°C. , is shown approximately by curve *E*. For example, if the motor is running at 80°C. , it will carry a steady current of 50 amperes, or a variable current of which the effective value is 50 amperes, for 30 minutes before reaching 100°C. If the average working temperature were less than 80°C. , the load could be applied for a proportionately longer period without causing the final temperature to exceed 100°C. The current referred to is the current per motor, of course, not the current per car; in making current-consumption tests on a car motor, therefore, the ammeter should be connected in series with the motor and not in series with the trolley. Most tramcars are equipped with at least two motors, and these are connected in series at low speeds, in which case the current in each motor is the same as the total current supplied to the car. At high speeds the motors are usually connected in parallel, and the current in each is then approximately half the total current. Curve *E* is useful in determining the maximum loads that a motor may take during times of unusually heavy load.

18. Relation Between Motor Torque, Gear Ratio, and Axle Torque.—Fig. 3 is drawn to show the relation between the forces acting on a car wheel, spur wheel, and pinion; r is the radius of the pitch circle of the pinion, r' that of the spur wheel, and r'' that of the car wheel. When current flows through the motor, the torque or twisting action that is exerted on the armature shaft and pinion depends on the value of the current and on the electrical design of the motor. The motor torque will be $F' r$, when F' is the force exerted at the pitch circle. Torque is

always expressed as a moment equal to force $\times$ radius, and if the force is given in pounds and the length of the radius in feet, the torque will be in pound-feet, which terms are those generally used in calculations of torque and power. For a given torque,

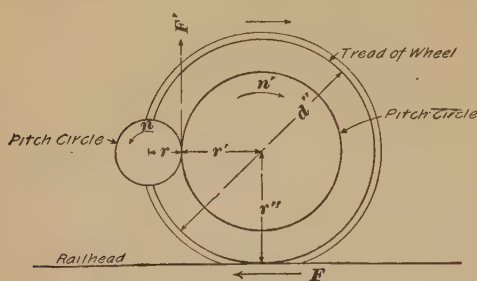


FIG. 3

F' will vary inversely as the radius of the pinion, but the product $F' r$ will remain constant, because if r is increased or decreased, F' will be decreased or increased by a proportionate amount. The torque

exerted on the car axle is $F' r'$ and is greater than $F' r$ because the radius, or lever arm r' , is greater than r . Since the number of teeth in any toothed wheel, the pitch or size of teeth being

fixed, is proportional to its diameter or radius, $\frac{r}{r'} = \frac{n}{n'}$, or

$r' = r \frac{n'}{n}$, where n is the number of teeth in the pinion and n' the

number in the spur wheel. The torque exerted on the axle is

$F' r'$, or $F' \times r \frac{n'}{n} = F' r \times \frac{n'}{n}$. But $F' r$ is the motor torque;

hence, the torque exerted on the axle is equal to the motor torque multiplied by the number of teeth in the spur wheel and divided by the number of teeth in the pinion, or, in other words, the torque exerted on the driving wheels is equal to the motor torque multiplied by the gear ratio.

19. Total Tractive Effort.—The total tractive effort F , Fig. 3, exerted at the rail head by both wheels, is equal to the torque $F' r'$

divided by the wheel radius r'' . Thus, $F = \frac{F' r'}{r''} = F' \frac{r' n'}{r'' n}$

$= \frac{F' r}{r''} \times \frac{n'}{n}$. Instead of the radius r'' , in feet, the wheel

diameter d'' , in inches, may be used, in which case $d'' = 2 \times 12 r''$, or

$$r'' = \frac{d''}{24}$$

Let F = tractive force, or effort, per motor, at the rail head, in pounds;

$F' r$ = motor torque, in pound-feet;

d'' = diameter of car wheel, in inches;

n' = number of teeth in spur wheel;

n = number of teeth in pinion.

Then,

$$F = \frac{24 F' r n'}{d'' n}$$

EXAMPLE.—A car is equipped with motors, each of which drives through a 15-tooth pinion and a 65-tooth spur wheel, and the car is mounted on 33-inch wheels. What will be the tractive effort due to each motor when the current is such as to produce a motor torque of 300 pound-feet?

SOLUTION.— $F' r = 300$, $d'' = 33$, $n' = 65$, $n = 15$. Hence,

$$F = \frac{24 \times 300 \times 65}{33 \times 15} = 945 \text{ lb., approximately. Ans.}$$

20. Determination of Speed of Car.—The number of feet per minute travelled by a car is $\frac{3.1416 d'' s'}{12}$, where d'' is the wheel

diameter, in inches, and s' the axle speed, in revolutions per minute. Since 1 mile per hour is equivalent to 88 feet per minute,

the speed S of the car, in miles per hour, is $S = \frac{3.1416 d'' s'}{12 \times 88}$, or

$$S = \frac{d'' s'}{336.1}$$

21. Change of Speed Due to Change in Gear Ratio.—In Fig. 2, the curves of tractive effort and speed are drawn for a gear ratio of 68 to 14, or 4.86, and for 33-inch wheels. Assuming that the wheel diameter remains unchanged, the effect of substituting gears having a ratio of 64 to 18 is that the gear ratio is decreased

from $\frac{68}{14} = 4.86$ to $\frac{64}{18} = 3.56$. From the formula in Art. 20,

the car speed is $S = \frac{d'' s'}{336.1}$. But s' , the speed of the axle, is

equal to $\frac{s}{n'}$ or $\frac{s n}{n'}$, where s is the motor speed, in revolutions per minute, and $\frac{n'}{n}$ is the gear ratio. Hence,

$$S = \frac{d'' s n}{336 \cdot 1 n'}$$

For a given current, the speed s of the motor has a certain fixed value, and if the gear ratio $\frac{n'}{n}$ is made smaller, that is, if

the number of teeth in the spur wheel is decreased and the number in the pinion correspondingly increased, it follows that, for any given current, the speed S of the car will be increased. The speed corresponding to the new gear ratio will be equal to the original speed multiplied by the original gear ratio and divided by the new gear ratio. In this case, the original gear ratio is $\frac{68}{14} = 4.86$ and the new gear ratio $\frac{64}{18} = 3.56$. When

each motor takes a current of 50 amperes, the speed with the original gear ratio is, from curve A , about 13.8 miles per hour. With the new gear ratio, the speed corresponding to the same current would be $\frac{13.8 \times 4.86}{3.56} = 18.8$ miles per hour. In order,

however, to drive the car at the higher speed, taking only the same current, the car would have to be made lighter. By calculating the speed corresponding to various currents, the dotted curve A' can be drawn to represent the variation of speed and current, corresponding to the gear ratio $\frac{64}{18}$, or 3.56.

22. Change of Tractive Effort Due to Change in Gear Ratio.

A change in gear ratio affects the tractive effort as well as the speed. For a given current, the power delivered by the motor remains the same, whatever the values of the speed and tractive effort. This is evident on referring to the curve C , Fig. 2, which shows the variation of the output of the motor, in horsepower, with variation in current. The power is constant if the value

of the current is fixed. A decrease in the gear ratio causes an increase in speed, as indicated by curve A' ; and, as the power curve C remains unaltered, the increase of speed corresponding to a given current must be accompanied by a decrease in tractive effort. This is also plain from the formula in Art. 19, in which any decrease in $\frac{n'}{n}$ makes F smaller. The tractive effort with

the new gear ratio will therefore be equal to the tractive effort with the original gear ratio, multiplied by the new ratio and divided by the original ratio. For example, in Fig. 2, the tractive effort corresponding to a current of 50 amperes is 750 pounds;

with the new gear ratio, the tractive effort will be $\frac{750 \times 3.56}{4.86}$

= 549 pounds. By calculating the tractive effort corresponding to a number of different current values, the dotted curve B' can be drawn, and curves A' and B' taken together represent the performance of the motor due to the change in gear ratio

from $\frac{68}{14}$ to $\frac{64}{18}$.

23. Effect of Change in Wheel Diameter.—With a given gear ratio and current, a reduction in the wheel diameter causes a corresponding reduction in the speed of the car, and vice versa. A decrease in the wheel diameter has the same effect on the speed of the car as an increase in the gear ratio.

24. Effect of Changing Gear Ratio on a Given Equipment. It is sometimes important to know the probable change that will be made in the speed of a given car when the gear ratio is changed, the weight of the car and all other parts of the equipment remaining the same. If the characteristic curves of the motor corresponding to the original gear ratio are available, the speed under the new conditions can be determined approximately as follows: Calculate two curves, similar to A' and B' , Fig. 2, as already explained, to suit the new conditions. From the known weight of car, the tractive effort can be determined approximately, and the speed and current corresponding thereto can be read off from the curves drawn for the new gear ratio.

For example, suppose that curves A and B represent the performance with the original gear ratio of $\frac{68}{14}$ and that the ratio is changed to $\frac{64}{18}$. Curves A' and B' then represent the performance under the changed conditions. With the original gearing, the tests showed that when the car ran at a speed of 13·8 miles per hour on the level, a current of 50 amperes per motor was required, and the corresponding tractive effort was 750 pounds per motor. If the weight of the car is unchanged, the increase in speed does not cause much change in the tractive effort, and for low speeds, such as are now under consideration, the change in tractive effort may be neglected, and the tractive effort taken as 750 pounds under the new conditions. With the new gear ratio, therefore, a tractive effort of 750 pounds corresponds to a current of about 61 amperes, as shown by curve B' , and to a speed of about 17·25 miles per hour, as shown by curve A' .

25. A change in gear ratio therefore causes an increase in speed, but the increase is not proportional to the change in the ratio of the gearing. If a change in gearing alone were considered, in the example given in the preceding article, the speed would be $\frac{13\cdot8 \times 4\cdot86}{3\cdot56} = 18\cdot8$ miles per hour. In order to

drive the car at this higher speed, more power must be supplied, and the current must therefore increase; in order to develop the increased power and torque, the motor will run more slowly. Because of this change in motor speed and current, the final steady speed of the car must be determined from characteristic curves for tractive effort and speed, drawn so as to take into account the change in gearing. Since, with a fixed weight of car, a decrease in gear ratio is accompanied by an increase in current, a point is soon reached beyond which any further change in gearing will cause serious overheating of the motors.

26. Motors on cars having low gear ratios take very large currents during the accelerating period unless the controllers are carefully handled. In case the weight of the car is not fixed, a motor can sometimes be geared for higher speed without

increasing the current. For example, a pair of motors might be taken off a heavy car and placed on a lighter one that requires a smaller tractive effort, at the same time putting in a gear with a smaller ratio. If the permissible current is the same in both cases, the motor torque and the speed of the armature will remain unchanged. Hence, assuming that the wheel diameters are the same on the two cars, a smaller tractive force and increased car speed are obtained by decreasing the gear ratio, since the armature speed remains constant.

EXAMPLES FOR PRACTICE

27. 1. If a car is mounted on 34-inch wheels and the motors have a gear ratio of $\frac{68}{16}$, what will be the total tractive effort per motor, when the motor torque is 300 pound-feet ? Ans. 900 lb.
2. If the gearing on a car is changed as indicated by the curves in Fig. 2, and if the tractive effort per motor remains constant, at 1,000 pounds, what will be the change in car speed caused by the change in gearing ? Ans. From $12\frac{1}{2}$ mi. per hr. to about 15.3 mi. per hr.
3. A car is mounted on 33-inch wheels and the motors have a gear ratio of $\frac{65}{15}$; what will be the speed of the armature, in revolutions per minute, when the car is running 16 miles per hour ? Ans. 706 R.P.M.

EXAMPLES OF TRAMWAY MOTORS

WESTINGHOUSE No. 200 MOTOR

28. **Field Frame.**—The Westinghouse No. 200 traction motor is designed to develop on the 1-hour rating, under ordinary tramway conditions, a tractive effort of 1,400 pounds, with 30-inch wheels, when running at a speed of 9 miles per hour; the motor is rated at 35 brake horsepower at this speed. The external appearance of the motor is shown in Fig. 4. The frame *a* is made in halves, as usual; the top half carries the armature-bearing boxes *b*, and extension arms are cast on to support the axle-bearing boxes *c*. The bearings are designed to allow the use of both oil and grease. The method of supporting the bottom

half of the frame on hinges *d* allows it to be swung down from the axle end for inspection of the armature, field coils, etc. The cable connections for the armature and field coils are shown at *e*. The inspection cover *f* at the commutator end of the motor gives access to the brush holders. The bolts *g* secure the pole pieces to the motor frame, and the lug *h* is provided for hanging the motor from the car truck. The forged-steel pinion *i* is normally enclosed, with the spur wheel which meshes with it,

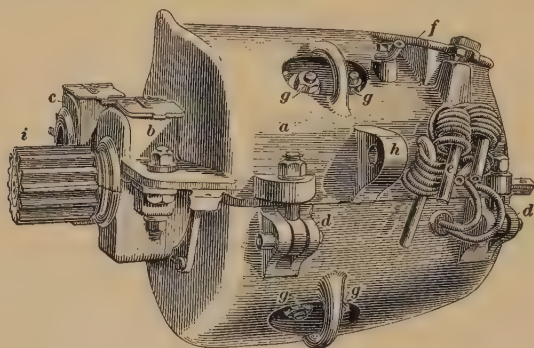


FIG. 4

in a cast-iron gear-case. The standard gear ratio for this motor is 4.86, obtained by the use of a 14-tooth pinion and a 68-tooth spur wheel.

29. Armature and Bearings.—A longitudinal section showing the general dimensions of the No. 200 motor is given in Fig. 5. The frame or casing is of cast steel and is split, as already stated, along the centre line, the top halves *a* of the bearing boxes being cast in one with the top half *b* of the frame. The lower halves *c* of the bearing boxes are made separate, so that the bottom half *d* of the frame may be lowered either with or without the lower halves of the bearings. The bearing shells are of cast iron, lined with white metal. The grease boxes and oil wells, respectively, are shown at *e* and *f*. Any oil that tends to pass along the shaft into the motor case is thrown off by the oil-throwing rings *g* and drains out through the openings *h*. A ball of waste *i* is placed inside the handhole cover *j* to absorb any oil which may pass the oil-throwing rings and enter the case.

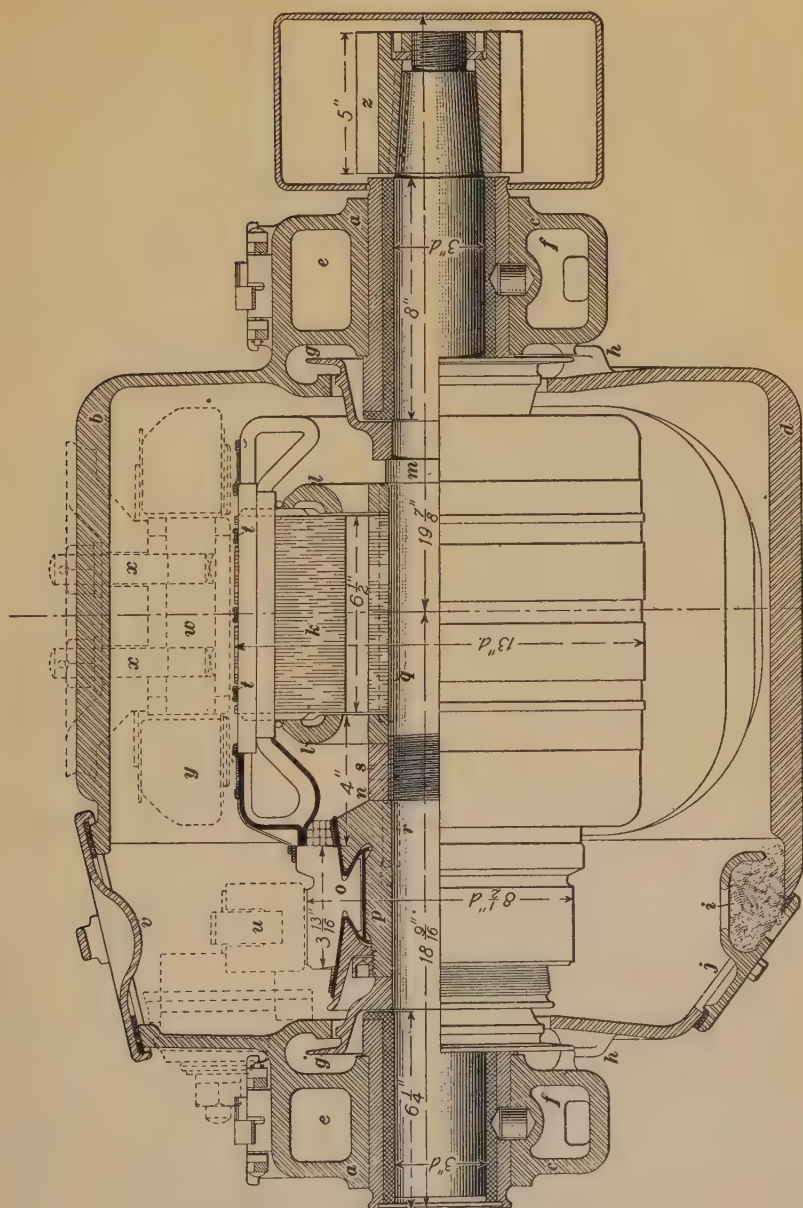


FIG. 5

30. Arrangement of Armature on Shaft.—The compactness of the motor on the shaft, in order to get the motor and gear-case on the car truck between the wheels, should be specially observed. The armature core *k* is pressed tightly between two end rings *l*, one of which bears against a collar *m* on the shaft, while a nut *n* is screwed hard up against the other. The nut *n* runs on a thread screwed on the shaft itself, and is locked by a setscrew *s*. The commutator *o* is secured on its own hub *p*, and keys *q* and *r* prevent the armature and the commutator from turning on the shaft.

31. Method of Securing Armature Windings.—The armature windings are secured in the slots by means of wire bands *t*. These are sunk in grooves in the armature core, so that the maximum amount of wear can be permitted in the bearings without the armature touching the pole pieces, and so that in the exceptional event of the armature being let down on the poles the binding wires shall not be torn off.

32. Brush Gear and Poles.—The brush gear of the motor is shown in dotted lines at *u*, Fig. 5, the cover *v* providing access to the brushes from the top of the motor. The section of the frame and pole piece at an angle of 45° , through the centre line of the poles, is shown at *w*. Each pole is built up of laminations riveted together, and is attached to the frame by means of the two bolts *x*. A cross-section of the field coils is seen at *y*. The pinion *z* is fastened to the tapered armature shaft by means of a nut screwed on the shaft end and countersunk into the boss of the pinion, and a key prevents its turning on the shaft. Since the pinion is overhung, the armature bearing at the pinion end is increased to 8 inches long, the length at the commutator end being 6 inches only.

33. Armature-Winding Connections.—A diagram of the connections of an armature coil of the No. 200 motor is shown in Fig. 6. The armature has 37 slots, with 3 commutator bars per slot, or 111 segments in all. The pitch of the coils is rather less than one-quarter of the complete circumference of the armature, or actually 8 slots; that is, from slot 1 to slot 9; the throw of the bottom leads of the coils is from commutator segment 17 to

segment 1, and of the top leads is from commutator segment 41 to segment 57. In commencing to rewind an armature with spare coils, a diagram similar to Fig. 6 should be drawn, and the figures followed in assembling and connecting up the armature coils. Looking at the armature from the commutator end, the lower half of one coil is assumed to go into the bottom of slot No. 1. To find the proper slot in which to put the upper

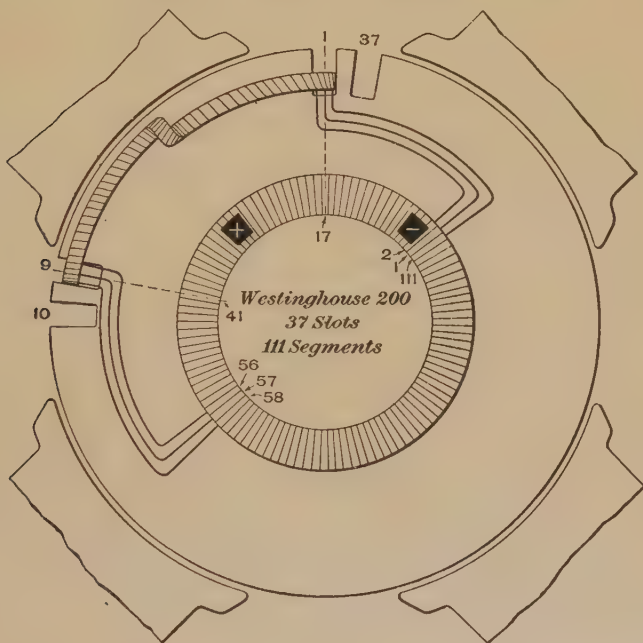


FIG. 6

half of the same coil, count the slots from right to left until slot 9 is reached ; in this slot the upper half of the coil is placed, and all other coils on the armature follow, with a similar pitch or span between the two sides. Each armature coil has three bottom ends or leads and three top leads, or six in all. These are usually coloured red, blue, and white. Find the commutator segment immediately below the middle of slot 1 and call it segment 17, and then count the segments backwards in a clock-wise direction until segment 1 is reached. To segment 1 is

connected the *middle* one of the three bottom leads, the other wires going to the adjoining segments on each side of segment 1. Now count the segments forward again from segment 1 in a counter-clockwise direction. It will be found that segment 41 is immediately opposite the centre of slot 9, and counting on until segment 57 is reached, nearly opposite to segment 1 on the commutator, the middle lead of the top half-coil must be connected to segment 57. The remaining coils on the armature must now be connected up in regular sequence until the winding is complete.

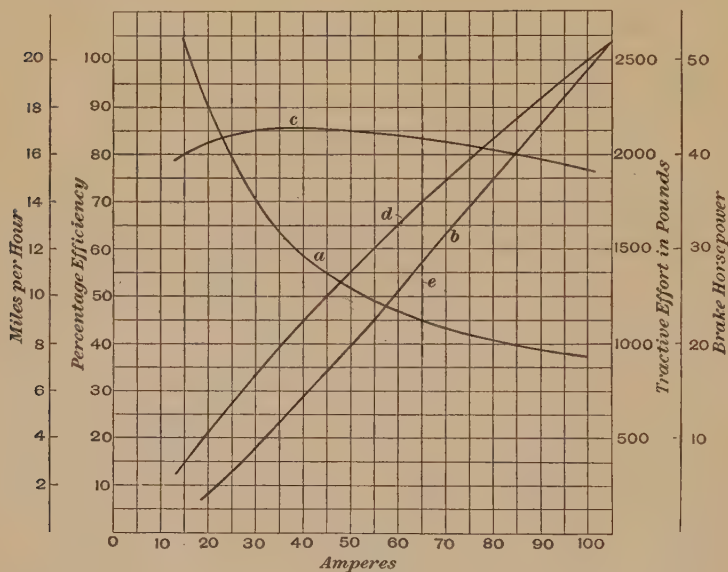


FIG. 7

34. Performance of Motor.—The characteristic curves or performance curves of the No. 200 tramway motor are shown in Fig. 7. Curves representing the variation of speed, tractive effort, efficiency, and brake horsepower are plotted on a base representing the current input of the motor, in amperes, when the full normal pressure of 500 volts is applied to the motor terminals.

The curve *a* representing the speed of the car, in miles per hour, and the tractive-effort curve *b* representing the force exerted

at the rail head, in pounds, are based on the standard gear ratio of 68 to 14 and car wheels 30 inches in diameter. Following the usual characteristic of the series-wound motor, the speed decreases with increased current, on account of the strengthening of the field flux when the current in the armature- and series-field windings increases. Thus, the current per motor is 17 amperes when the speed of the car is 20 miles per hour, 32 amperes when the speed is 13.5 miles per hour, and 83 amperes when the speed is 8 miles per hour.

35. Tractive Effort.—The tractive effort of the motor, as shown by curve *b*, Fig. 7, increases with increase of current independent of the speed of the car. Since the motor torque, and therefore the tractive effort, are proportional both to current and field flux, the tractive-effort curve bends upwards, showing that the tractive effort increases even more rapidly than the current increases, due to the strengthening of the field flux. The tractive effort is about 190 pounds when the current per motor is 20 amperes, 500 pounds at 32 amperes, and 2,000 pounds when the current is 84.5 amperes.

36. Efficiency and Output.—The efficiency of the motor, as shown by curve *c*, Fig. 7, is a maximum at about 86 per cent. when the motor current is 40 amperes. At lower currents the efficiency is less, owing to the fact that the combined iron losses and friction losses do not decrease as rapidly as the current decreases, and at greater currents the efficiency falls because the copper losses increase at a greater rate than the current. The efficiency falls to 80 per cent. when the motor current is 85 amperes.

The brake horsepower of the motor is measured with the gear in operation; that is, the brake-horsepower curve *d*, Fig. 7, represents the horsepower actually delivered to the car axle. The horsepower increases proportionately to the product of speed, tractive effort, and efficiency. The increase in brake horsepower is thus nearly proportional to the increase in current, but above 40 amperes the actual increase is slightly less than proportional to the current, because the efficiency falls off as the current increases. When the motor takes 15 amperes it develops

7.5 brake horsepower, at 32 amperes 17.5 horsepower, and at 80 amperes 42 horsepower. The vertical dotted line *e* denotes that rating of the motor corresponding to a temperature rise of 75° C. after 1 hour's run. Under these conditions the motor takes 65 amperes while developing 35 brake horsepower.

BRITISH THOMSON-HOUSTON G.E. 52 MOTOR

37. Field-Frame Construction.—As an example of a small motor rated at 20.5 horsepower and intended for driving light single-truck cars, the G.E. 52 motor of the British Thomson-Houston Company will first be described. A rear view of the motor in Fig. 8 shows the general shape of the field frame, which, as in all modern traction motors, is shaped so as to enclose completely the armature commutator, brushes, and field coils.

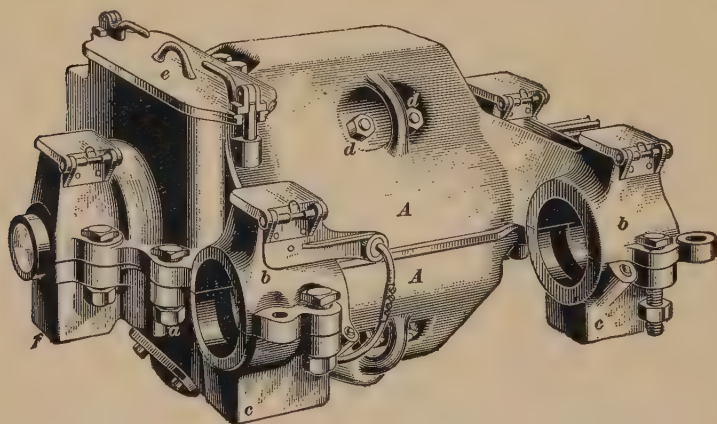


FIG. 8

The field frame *A* is roughly hexagonal in outline and is made in halves, which are held together by bolts. The two arms *b* extending from the back of the motor carry the upper halves of the axle bearings, which are provided with grease boxes. The lower bearing blocks *c* are fitted with oil wells, and oil is fed into the bearing by means of pieces of felt underneath the axle. The bolts *d* hold the pole pieces in place. The removable cover *e* allows access to the commutator and brush holders. The lower

halves f of the armature bearings are separate from the lower half of the field frame A , and by unbolting the field frame, but not the bearings, and leaving the latter in position, the lower half of the field frame may be swung down for inspection or repair of the armature or field coils, leaving the armature in the upper half, as shown in Fig. 9. By unbolting the armature bearings, the armature can be lowered with the field, thus leaving the upper field coils and pole pieces exposed, as shown in Fig. 10.

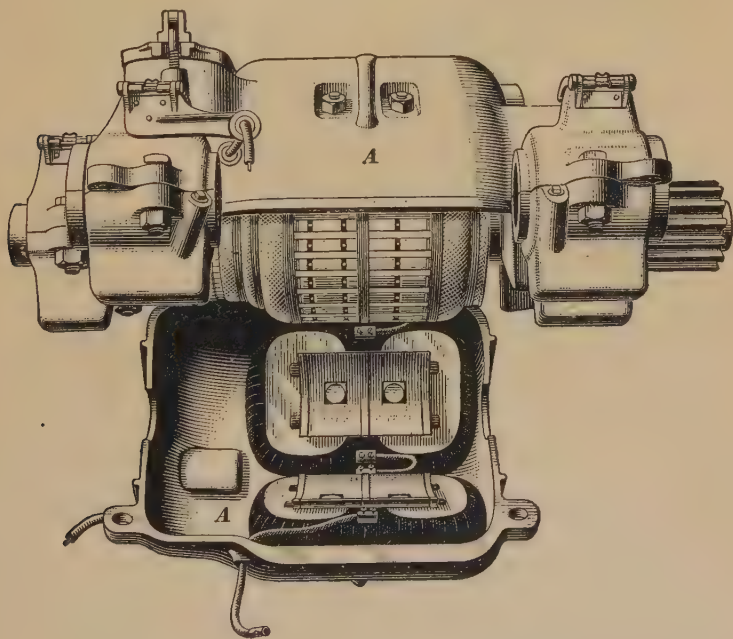


FIG. 9

38. Pole Pieces.—The motor is provided with four flanged and laminated pole pieces ; the flanges serve to hold the field coils in place, while the lamination of the pole pieces serves to keep the iron losses in the pole faces low, thus reducing the heating. The pole pieces are made of iron plates of the shape shown by the full lines of Fig. 11 (*b*). In building up the pole piece every other plate is reversed, with the result that, along the centre line of the pole, the plates are close together and the

pole face is solid, but at the pole horns only half of the plates extend on each side, as shown in Fig. 11 (a). This construction produces a *fringed* magnetic field under the pole horns. This fringe largely prevents distortion of the magnetic field, and

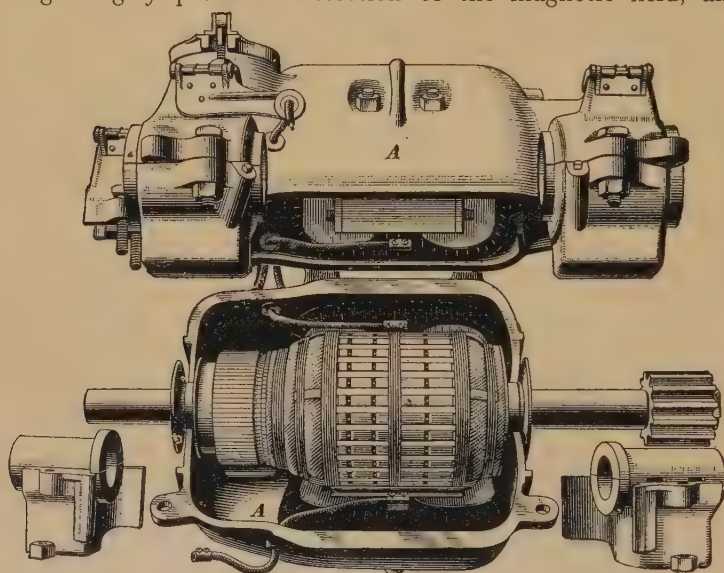


FIG. 10

provides the proper field for reversing the current in the armature coils passing under the brush with but little sparking. Each pole piece is held in place by two bolts which pass through the casing.

39. Field Coils.—The field coils are former-wound, and in

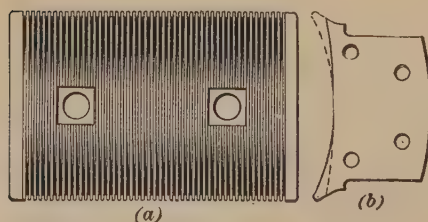


FIG. 11

course of winding, the asbestos-covered wire is treated with a mixture of chalk and japan; the whole is afterwards baked. The coils are well insulated with tape and insulating varnish, and are finished with a glazed

surface that prevents moisture from getting into the coils.

40. Brush Holders.—Traction-motor brush holders are fixed permanently at the neutral point and cannot be shifted, as in the case of most other direct-current machines. The reason for this is twofold: In the first place, the motor has to run in either direction; and in the second place, the variations in load are so sudden that the use of any brush-shifting arrangement to alter the position of the brushes to suit the load is out of the question. The brush holders are, however, mounted so that they can be moved radially toward the centre of the commutator as the latter wears away.

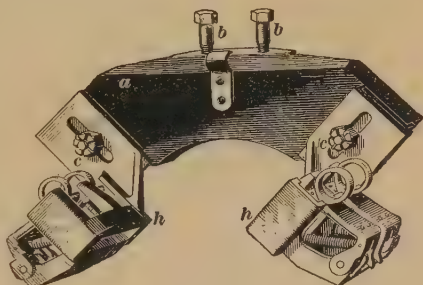


FIG. 12

Fig. 12 shows the brush holders and brush-holder yoke of the G.E. 52 motor. The yoke *a*, which is made of well-seasoned hardwood treated with an insulating solution, is bolted to the upper field frame by means of bolts *b*. The brush holders *h* are secured against brass slides on the yoke *a* by means of bolts *c*. Carbon brushes are always used for traction motors, the dimensions of each brush in this instance being $2\frac{1}{4}$ inches by $1\frac{1}{4}$ inches by $\frac{1}{2}$ inch; two brushes are used in each holder.

41. Armature.—Fig. 13 shows a half section of the G.E. 52 armature, and its construction is typical of many of the traction-motor armatures now in use. The core is provided with 29 slots. Each slot contains one side of 6 coils, so that there are 87 coils altogether, and the commutator has 87 bars. The winding is called a six-turn winding, to distinguish it from the four-turn winding which is sometimes used with the same size of machine, but which has only 4 half-coils per slot. The coils of the six-turn winding are bunched in groups of three, one side of one bunch going into the bottom of a slot, and one side of another into the top of the same slot. The laminated armature core is shown at *a*, and at *b* and *b'* the upper and lower halves,

respectively, of two coils lying in the same slot. The ends of the coils, where they project from the core, are supported and protected by the end shield *c*. The leads from the coils are connected to the commutator bars *d*, which are mounted between V rings,

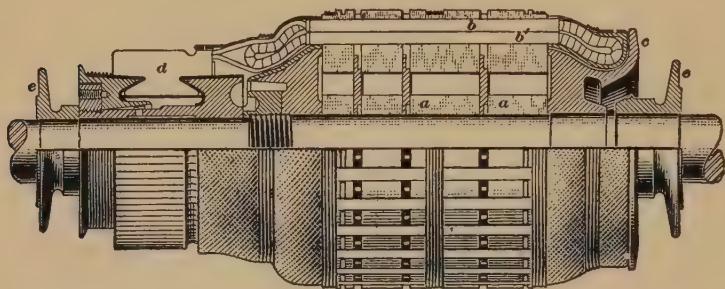


FIG. 13

as shown. The oil-throwing flanges *e, e* prevent grease and oil working their way into the armature from the bearings.

42. Armature-Coil Connections.—A diagram of the con-

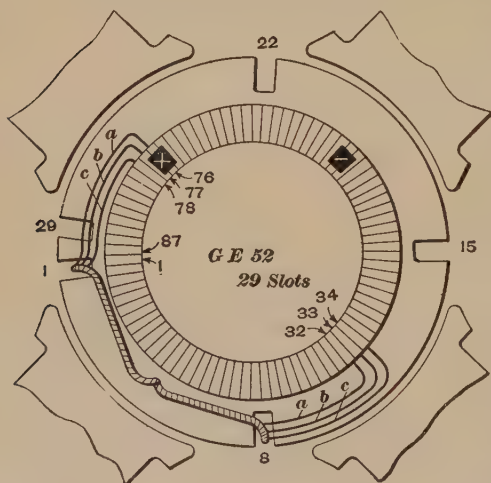


FIG. 14

nections of an armature coil of the G.E. 52 six-turn motor is shown in Fig. 14. There are 29 slots and 3 commutator segments per slot, making the total number of segments 87. The leads of one coil to the commutator segments are lettered *a, b*, and *c*. If the segment under the centre of slot 1 is called segment

No. 1, the bar to which the middle lead of the bottom half-coil is to be connected may be found by counting round in a

counter-clockwise direction past the coil until segment 77 is reached. The same segment may be found by counting 12 segments back in a clockwise direction from the starting point 1. The middle lead from the top half-coil is connected to segment 33, as shown. The pitch of the coils is 7, or from 1 to 8.

43. Characteristic Curves of G.E. 52 Motor. — The various characteristics of the G.E. 52 six-turn motor are shown in Fig. 15. Curve *a* shows the variation of speed with the load on the motor,

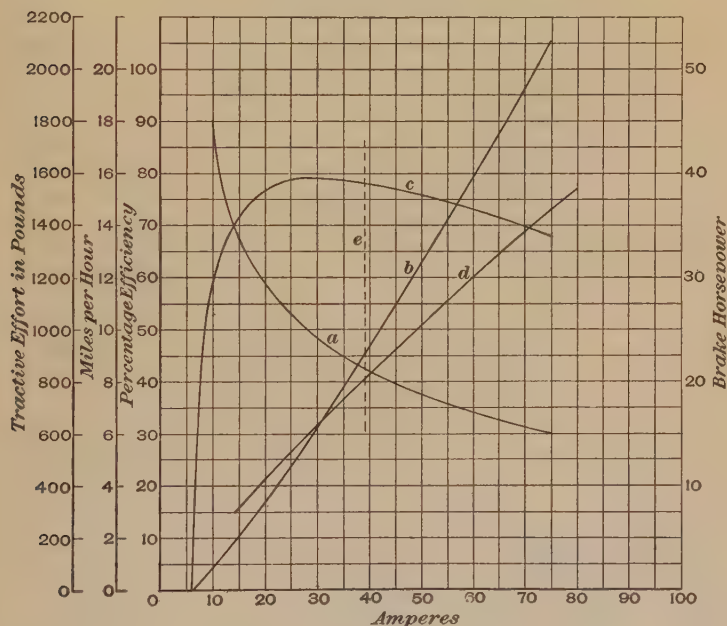


FIG. 15

and curve *b* shows the tractive effort at the rail head, in pounds, for various values of current. The efficiency curve *c* shows the efficiency of the motor, including the gearing and car-axle friction. The brake horsepower is given by curve *d* and represents the power delivered at the car axle. The output of the motor corresponding to a temperature rise of 75° C. after 1 hour's run is 20.5 brake horsepower, corresponding to a current input of 39 amperes, as shown by the vertical dotted line *e*.

DICK-KERR 25A MOTOR

44. **General Features.**—A view of a Dick-Kerr traction motor, known as the D.K. 25A, is shown in Fig. 16. It is rated at

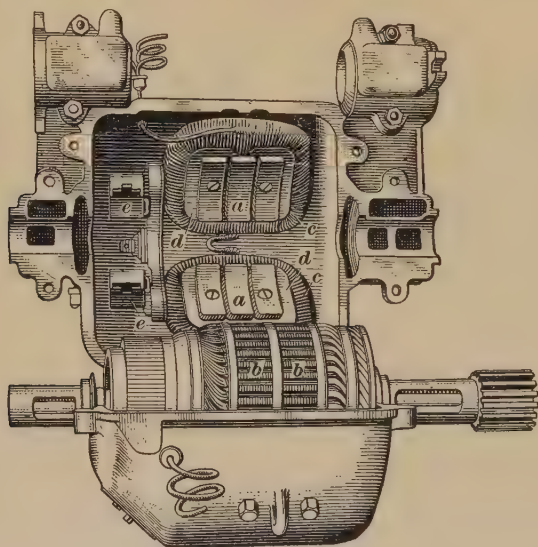


FIG. 16

26 horsepower and is suitable for single-truck double-deck cars. The illustration shows the motor with the upper half of the frame

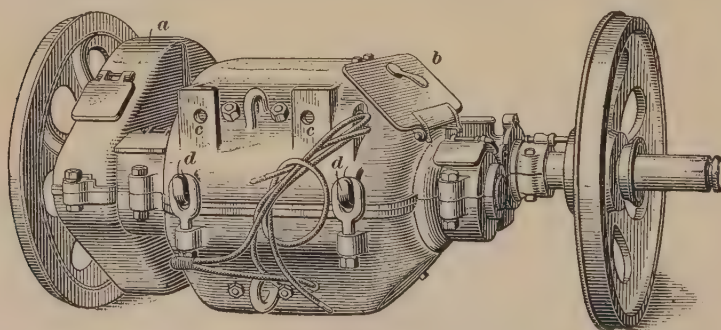


FIG. 17

raised. The field poles *a* are laminated and arranged with two ventilating ducts in each, so that a circulating current of air is

maintained from the armature ventilating ducts *b* through the field cores and round the back of the field coils against the motor shell, thus helping to keep the motor cool. The field coils *c* are held in place by bronze frames *d*. The brush holders are seen at *e*. In Fig. 17 is shown the motor mounted on the axle with the gear-box *a* in place. The door *b* is for access to the commutator, and the lugs *c* are bolted to a suspension bar

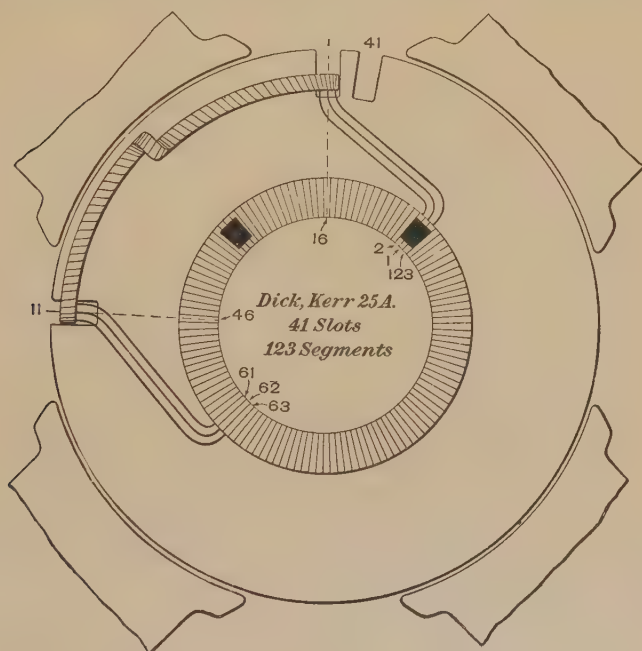


FIG. 18

to carry the motor on the truck. The motor is fitted with a 5 to 1 gear ratio. The eyebolts *d* are used for bolting the top and bottom halves of the frame together, and fit over hooks on the upper half of the frame.

45. Armature-Coil Connections.—The armature of the Dick-Kerr 25A motor has 41 slots and 123 commutator segments. The field poles are on the diagonals, and in order to bring the brushes opposite the centres of the poles the armature leads are

given a throw of about one-eighth, as shown in Fig. 18. The commutator segment under the centre of slot 1 is taken as 16,

and the middle lead from the bottom coil in the slot is connected to commutator segment 1, counting back in a clockwise direction. The other terminal of the coil is connected to segment 62. The pitch of the coils is 10 slots, or from slot 1 to slot 11.

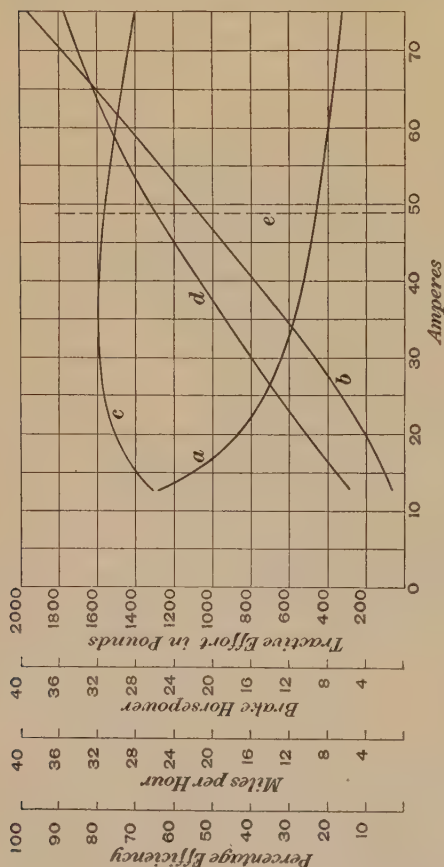


FIG. 19

46. Characteristic Curves of D.K. 25A Motor.—The curve *a*, Fig. 19, shows the variation in speed with the load on a D.K. 25A traction motor fitted with a gear ratio of 71 to 14. The tractive-effort curve *b* and horsepower curve *d* are plotted as in the previous cases. The efficiency curve *c*

shows the net efficiency of the motor, including the gearing, and indicates that the maximum efficiency is obtained when the speed is about 11.5 miles per hour, the horsepower about 19, and the current 35 amperes. The efficiency of the motor under these conditions reaches just 80 per cent. The vertical dotted line *e*, at a current of 49 amperes, corresponds to a temperature rise of 75° C. after 1 hour's run at a rated output of 26 horsepower.

DICK-KERR INTERPOLE MOTOR

47. **Use of Interpoles.**—It was explained in connection with stationary motors that **interpoles** are small poles placed between the main field poles and wound with series coils, their function being to improve commutation by providing a field of the proper strength and direction to reverse the current in the coils short-circuited by the brushes during commutation. In this way, sparkless commutation is secured. The series coils of the interpoles are connected in series with the armature, so that the commutating field produced is always proportional to the current flowing. An interpole motor will operate without

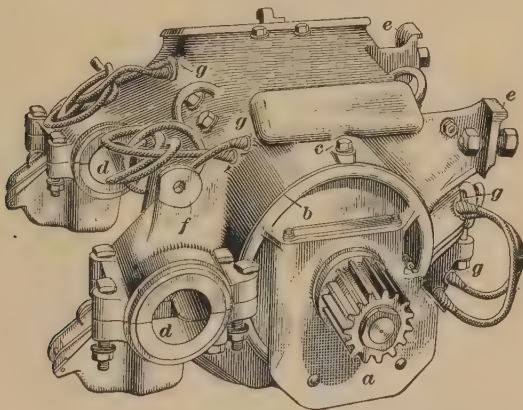


FIG. 20

sparking even on heavy overloads, and with interpoles it is possible to use a smaller and lighter motor in any given case than if no interpoles were provided. Owing to the absence of sparking at the brushes of interpole motors, it is possible that pressures of 800 to 1,200 volts may come into use for the operation of tramcars. There are a few installations on the Continent using supply pressures of 800 volts or more, and the success of these has proved the feasibility and safety of high-voltage systems.

48. **General Construction.**—The Dick-Kerr interpole traction motor, known as the D.K. 9, is shown in Fig. 20. It is designed for an output of 40 horsepower at the standard 1-hour rating.

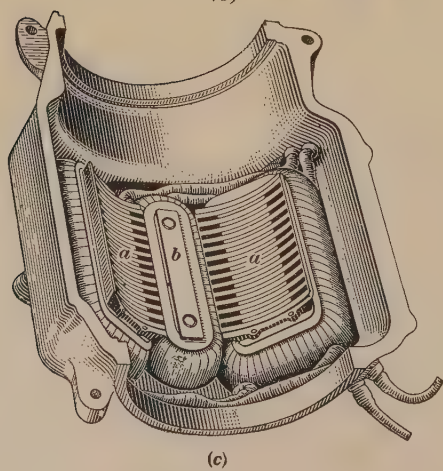
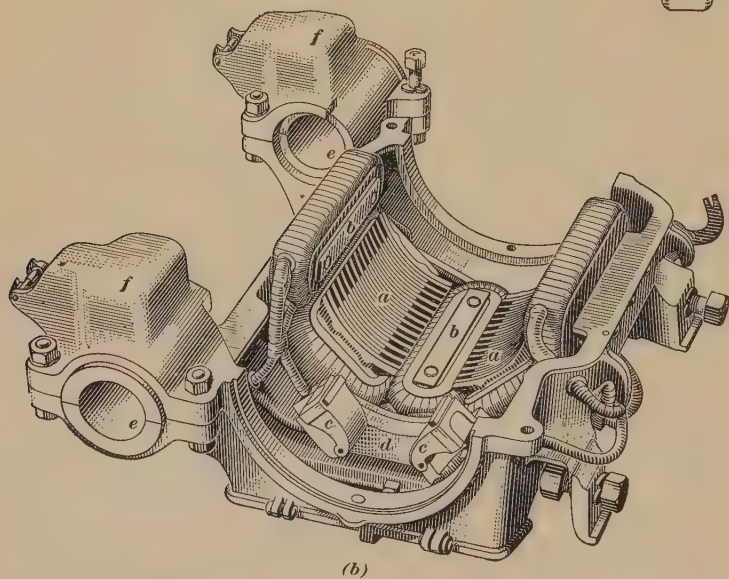
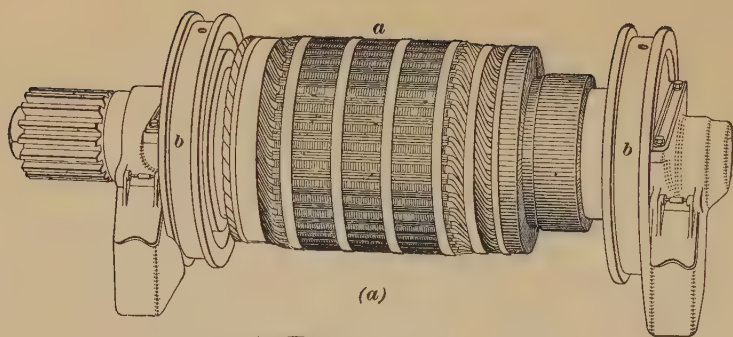


FIG. 21

The armature-bearing boxes and motor end casings *a* are cast quite separate from the main motor frame, and are held in position between the top and bottom halves of the frame by means of a circular tongued-and-grooved joint *b*. Setscrews *c* prevent the bearing boxes turning in the frame. The supporting arms for the axle bearings *d* are cast with the upper portion of the frame, as usual. The lugs *e* are provided for suspending the motor from the truck, and the lug *f* is provided for supporting the gear-case, which encloses the pinion and spur wheel. The armature and field-coil leads are brought out of the case at the points *g* for convenience in connecting up and testing.

49. Views of the main parts of the D.K. 9 tramway motor are given in Fig. 21 (*a*), (*b*), and (*c*). In view (*a*) is shown the armature *a* mounted in the end casings *b*, which are circular in form and fit into circular openings in the motor frame, thus ensuring the proper centring of the armature. In view (*b*) is shown the upper part of the casing, inverted so that the two main field poles *a* and the three interpoles *b* which are attached to it may be seen. The brush holders *c* are attached to a brush yoke *d*. The axle bearings *e* are lubricated by means of wicks which dip into the oil reservoirs *f*. The lower part of the casing is shown in view (*c*) with the main poles *a* and interpole *b*.

TRAMWAY CONTROLLERS

RHEOSTATIC CONTROL

50. **General Principles.**—Since the speed of a series motor can be varied by inserting an adjustable resistance in series with it, the simplest method of controlling the speed of street cars is by means of a series resistance used in connection with a switching device called a **controller**, by means of which the amount of resistance in circuit can be varied. This is known as the **rheostatic method of control**. It is used in cases where only one motor is to be controlled and where gradual variations in speed are desired, as for cars driven by a single motor, and to some extent in connection with mine-haulage plants and cranes.

Some of the more important features of rheostatic control will be considered briefly; this will also serve as an introduction to the series-parallel method of control for two motors which is to be described later.

RHEOSTATIC CONTROLLER

51. General Construction.—A rheostatic controller, known as the **R11** controller, made by the British Thomson-Houston Company for the control of cars, haulage locomotives, or crane motors

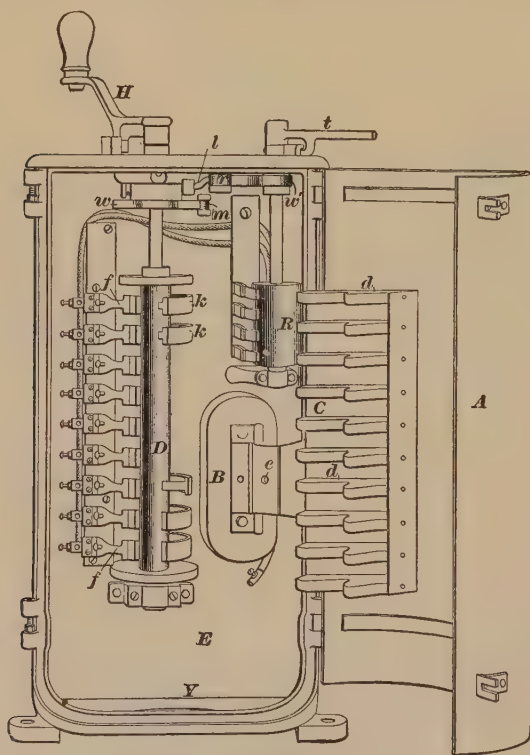


FIG. 22

is shown in Fig. 22 with the cover *A* thrown back to expose the working parts. This controller will be considered in detail because it contains many of the features found on controllers

used on tramcars. It is designed to control one 50-horsepower 500-volt motor or one 25-horsepower 220-volt motor ; that is, its contacts are large enough to carry about 75 amperes. The changes in the connections to the resistance are effected by a *drum*, *cylinder*, or *barrel*, called the **power drum**, or **barrel**, to distinguish its duty from that of drums used in controllers for reversing and braking. The drum *D* is provided with contact segments *k* that pass under and make electrical connection with the fingers *f* when the drum is rotated by means of the handle *H*. Each finger and contact segment is separated from the adjacent ones by fireproof insulating partitions *d* carried on a frame *C*. The latter is swung into position close to the power drum and held in place by a screw through the hole *e*. The frame *C* also forms one pole of the *blow-out magnet* *B*, the other pole being formed by the iron back *E* of the controller. The wires are brought into the controller through an opening in the bottom *Y*.

52. Star, or Index, Wheel.—In order to compel the power cylinder to take up definite positions corresponding to the various steps, and to prevent it remaining in any intermediate position, there is a **star wheel**, or **index wheel**, *w*, Fig. 22, attached to the shaft. This wheel engages with a spring-actuated roller *m*, which is pulled by its spring into the various notches on the star wheel as the latter rotates and allows the cylinder to remain only in the proper positions. It is the action of this star wheel and roller that gives the movement of a controller handle its springy feeling.

53. Reverse Cylinder.—The reversing switch, called also the **reversing drum**, **barrel**, or **cylinder**, is shown at *R*. This is much smaller and simpler than the power cylinder, and in this instance is mounted in the upper right-hand corner of the controller. Its sole function is to reverse the armature connections, when no current flows, in case it is desired to run the car in the opposite direction. The reversing drum is not intended to switch the current on or off or to effect any changes in the resistance. For this reason the reverse cylinder is not provided with any device for suppressing arcing, and its contact fingers are made somewhat lighter than those on the main cylinder.

54. Interlocking Devices.—In order to ensure that the reverse cylinder shall not be moved while current is flowing, the controller is provided with an interlocking device that makes it impossible to move the reverse cylinder unless the power cylinder is at the off-position. The reverse cylinder shaft is provided with a star wheel w' , Fig. 22, which has three notches, corresponding to the off-, ahead-, and back-positions of the handle t . The roller r engages with this star wheel, and a link l is attached to the lever carrying the roller. The hub of the star wheel w on the power drum has a notch in it that comes opposite the end of the link l when the power drum D is at the off-position, and when the reverse handle t is moved, the end of link l can pass into the notch and allow the roller r to pass over the projections on the star wheel w' ; when roller r rests in a notch on star wheel w' the link l falls back far enough to allow the power drum to be turned. At any position of the power drum other than the off-position, there is no notch opposite the end of link l ; and if any attempt is made to move reverse handle t , link l butts against the hub and the reverse cylinder is locked.

When the reverse lever is turned to the position marked *Ahead*, the car runs forwards, and when it is turned to the position marked *Back*, the car runs backwards. The respective positions are often arranged so that the reversing lever points in the direction in which the car is to run, forwards or backwards, as the case may be.

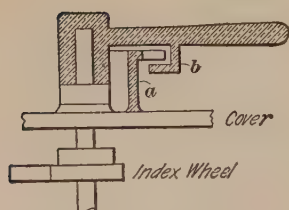


FIG. 23

The reverse handle is also fitted with a locking arrangement, so that it cannot be removed unless the power drum is at the off-position. An angle guard a , Fig. 23, is cast on the cover of the controller and overhangs a hook b cast on the handle. A notch c is cut in the guard, so that the handle of the reverse drum can be lifted off at the off-position and no other.

55. Magnetic Blow-Out Device.—The R11 controller is of the magnetic blow-out type, so called because a magnetic field is used to extinguish the arc formed at the contact tips when a circuit carrying current is broken. Were the arc not extinguished promptly, it would cause blistering and burning of the contacts. This method of preventing damage due to arcing has proved very effective, and it is used on most modern tramway controllers. The coil *B*, Fig. 24, sets up the magnetic field necessary to blow out the arc, and is therefore called the **blow-out coil**. Fig. 24 shows in plan the relative positions of the pole piece *C* of the blow-out coil, cylinder *D*, and the controller

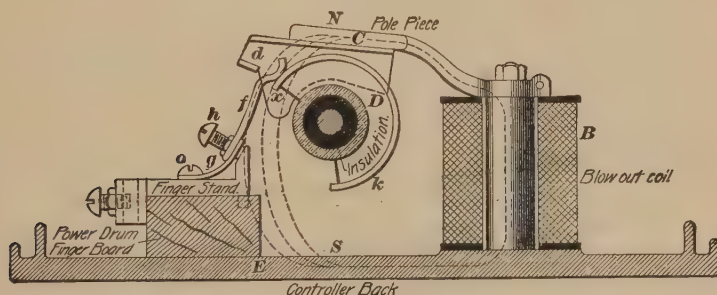


FIG. 24

back *E* when the pole piece is swung into position. The insulating partitions *d*, made of vulcabeston (vulcanized asbestos), pass between the contact segments as shown.

56. All the current supplied to the car passes through the blow-out coil *B*, Fig. 24, so that the strength of the magnetic field set up between poles *N* and *S* increases with an increase in the strength of the current. The direction of the field is indicated by the curved dotted lines. When the cylinder is revolved far enough, tip *x* of segment *k* leaves finger *f* and an arc tends to form between *x* and *f*. This arc acts in the same way as a flexible wire carrying current, and is therefore forced across the field and stretched out until it is broken. The action is practically instantaneous, so that there is little or no burning of the fingers and segments. The fingers *f* are stamped out of thick copper ; each finger is attached to a flat phosphor-bronze

spring *g*, which is in turn fastened to the cast-brass finger stand by means of screws *o*, so that fingers which are accidentally broken or burnt can be replaced at any time. Screw *h* is provided in order to adjust the pressure with which the fingers press on the segments and the amount that the finger drops when the segment passes from under it. The fingers should be adjusted so as to drop about $\frac{1}{32}$ to $\frac{1}{16}$ inch. In a tramway system employing a large number of cars the controllers and the brush gear of the motors should be inspected regularly when the cars are out of service; the brushes should then be trimmed and the contact segments of the controllers rubbed with a little vaseline, so as to prevent wear and cutting.

57. Controller Diagram.—The R11 controller has six points, and a diagram of the cylinder with the various connections,

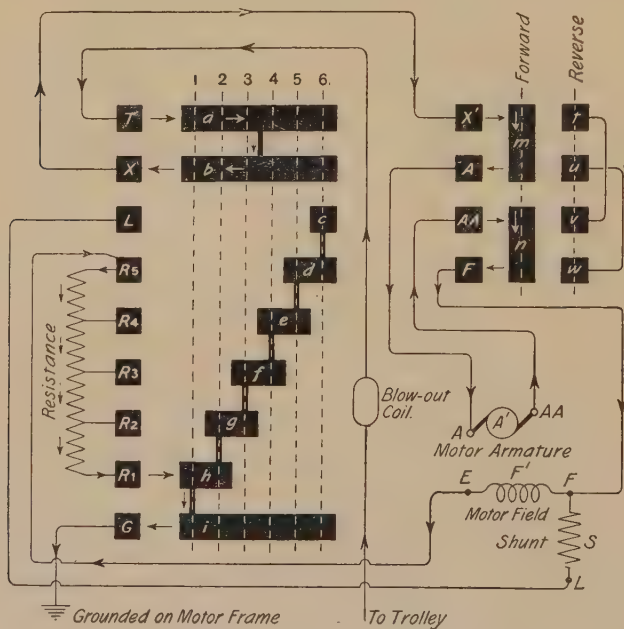


FIG. 25

called a **controller diagram**, is shown in Fig. 25. This diagram shows the connections suitable for controlling a single motor,

of which A' and F' are the armature and field, respectively. In this diagram and in those to follow, the cylinder segments are indicated by black bands, which represent the segments straightened or developed out flat. The fingers on the connection boards of the power cylinder and the reverse cylinder are represented by vertical rows of black squares or spots. The vertical dotted lines represent the various positions of the cylinder, and in studying the connections made by moving the controller handle to any given position, the developed cylinder can be considered as sliding under the contact fingers until the fingers are on the vertical dotted line corresponding to the notch, or position, on which the handle is placed. In this case, the power cylinder has two sets of contact segments. Contact segments a and b are connected together electrically, as shown by the black line drawn from one to the other, but they are insulated from c, d, e, f, g, h , and i , which are all connected together. Groups of adjacent segments that are electrically connected, as in this case, are often made of a single casting.

58. Controller Circuits.—On the first notch, fingers $T, X, R1$, and G make contact with their respective cylinder segments; none of the other segments and fingers is in contact. The path of the current on the first notch, when the fingers are on the vertical dotted line numbered 1 , Fig. 25, and the reversing switch is closed in the forward position, is indicated by the arrows, and is: trolley-blow-out coil- $T-a-b-X-X'-m-A-A$ -armature $A'-AA-AA-n-F-F$ -field $F'-E-R5$ -through the whole of the starting resistance- $R1-h-i-G$. The last contact finger G is earthed, or grounded, on the motor frame, thus completing the circuit from the trolley to the rail.

On the second notch, finger $R2$ touches segment g , and when the current reaches $R5$ it flows through three sections only of the resistance, because when it reaches $R2$ it takes the path $R2-g-h-i-G$. On the third notch, the section of resistance between $R2$ and $R3$ is cut out. On the fourth notch, that between $R3$ and $R4$, and on the fifth notch all the resistance is cut out, the path of the current then being: trolley-blow-out coil- $T-a-b-X-X'-m-A-A-A'-AA-AA-n-F-F-F'-E-R5-d-e-f-g-h-i-G$. The fifth

notch therefore allows the full line voltage to be applied to the motor terminals, and gives the highest speed that can be attained by simply cutting out resistance.

59. Use of Diverter for Maximum Speed.—On the R11 controller a *shunt* or *diverter* *S*, Fig. 25, is used, so that on the sixth notch the shunt will be connected across the terminals of the motor field coil, thereby weakening the field and increasing the speed. One end of the shunt is attached to point *F* and the other to finger *L*. On the sixth notch, the path of the current is the same as on the fifth up to the point *F*; there the current divides, part of it taking the path *F-F'-E-R5-d-e-f-g-h-i-G*, and the other part the path *F-S-L-L-c-d-e-f-g-h-i-G*, thus reducing the current in the field coil. Instead of weakening the field by means of a shunt, the same effect can be obtained by winding each field coil in two sections, joining up the field winding in two portions in series, and connecting an intermediate tapping point to the wire *L L*. When the controller handle is on the last position, part of the field winding is cut out, thereby weakening the field and increasing the speed. These so-called *shunt* or *diverter methods* of control are not much used for traction work; they introduce undesirable complications into the field connections of the motor, and it has been found that a sufficient range of speed can be secured without them. The controller could be used without a shunt *S* by simply omitting the connection *L L*, in which case the speed on the sixth notch would be the same as on the fifth.

60. Operation of Reverse Drum.—If the motor is to be reversed, the reverse drum is rotated by the handle into the reverse position, bringing contacts *t, u, v, w*, Fig. 25, under fingers *X', A, AA*, and *F*, respectively. When the current reaches *X'*, it therefore takes the path *X'-t-v-AA-AA-A'-A-A-u-w-F* and thence to the motor field circuit. In other words, the current flows to the brush at the *AA* side of the armature instead of to the brush at the *A* side as before, but it still flows through the field winding from *F* to *E*, in the same direction as before, thus reversing the current through the armature, but not through the field.

Trolley Base

Hood Switch

Controller No. 2

Controller No. 1

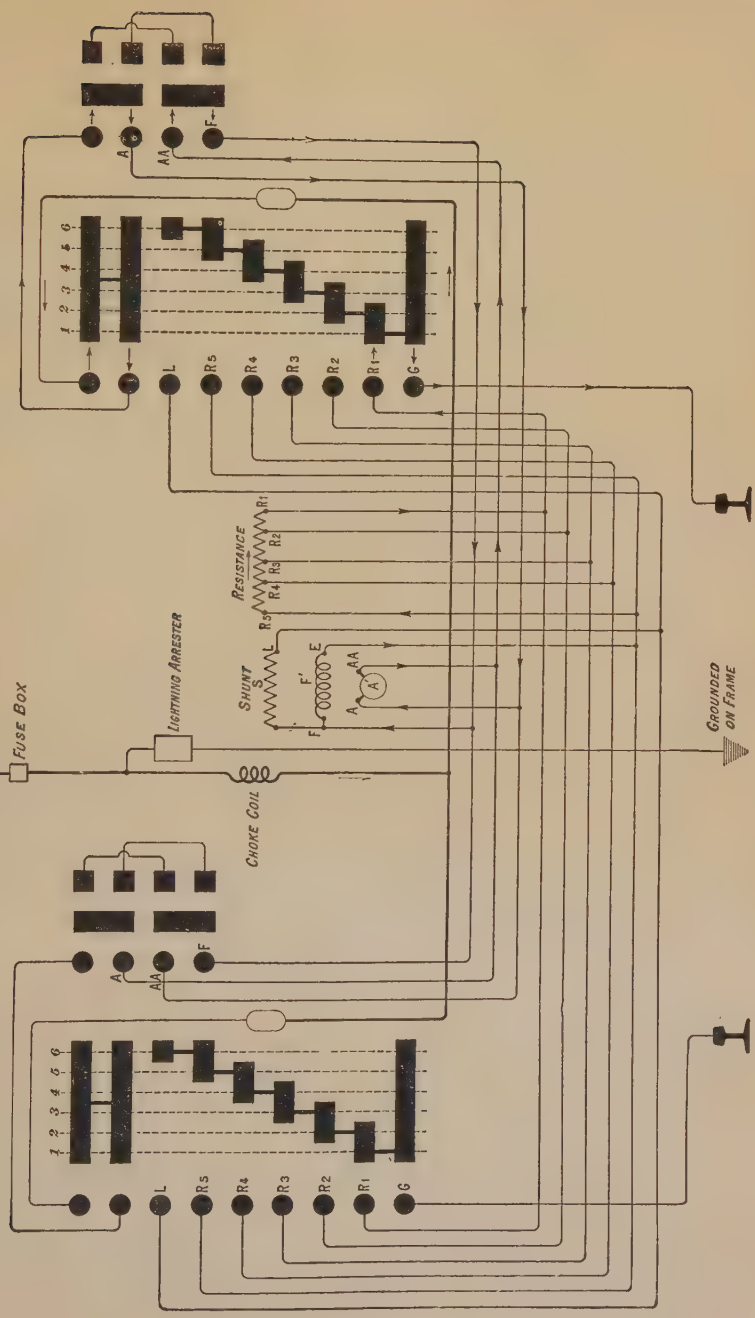


FIG. 26

CAR-WIRING DIAGRAM FOR R11 CONTROLLERS

61. Use of Two Controllers.—In Fig. 25, only one controller is shown, but on a car or mining locomotive two controllers, one at each end, are usually necessary in order that the driver may control the car or locomotive from either end. Fig. 26 shows the method of connecting two R11 controllers together in parallel, either being available for controlling a single motor. The corresponding terminals of the power drums of the two controllers are connected together by wires that run the whole length of the car. However, on the reversing drums the terminal marked *AA* on controller No. 1 is connected to the terminal marked *A* on controller No. 2, and *AA* on controller No. 2 is connected to *A* on controller No. 1. It is necessary to interchange the armature wires in this way so that the reverse handle will point in the direction in which the car is to run, at whichever end the driver may be standing.

62. When either of the two controllers on a car is in use, the other is at the off-position, because only one handle is supplied for the reverse cylinder, and this cannot be removed until the power is switched off. The arrowheads show the path of the current when controller No. 1 is on the first notch. This is practically the same as that shown in Fig. 25, except that the arrangement of the parts is a little different. The wires in this and in the following diagrams are not supposed to be in electrical connection with each other where they cross, unless there is a round dot placed at their point of intersection. A convenient method by which the various combinations and connections of a controller may be represented diagrammatically, step by step, is shown in Fig. 27. The first five steps differ from one another in the amount of resistance included in circuit, and the last step is the same as the fifth, with the exception that the field *F'* is shunted.

63. Arrangement of Resistance.—If a controller resistance is used continuously to control the speed of any motor, it must be proportioned so as to avoid overheating, and so that all the resistance notches may be used as running notches. With

ordinary tramcars, the controller resistance is not intended to be used for speed-controlling purposes. It is only intended to give the car a smooth start, and should not be kept in circuit when the car has once got well under way. Before leaving the study of the rheostatic controller, it should be noticed that the resistance coils are shown connected on the earthed side of the motor, so that the current first enters the motor, and the motor is subjected to the full line voltage during both running and

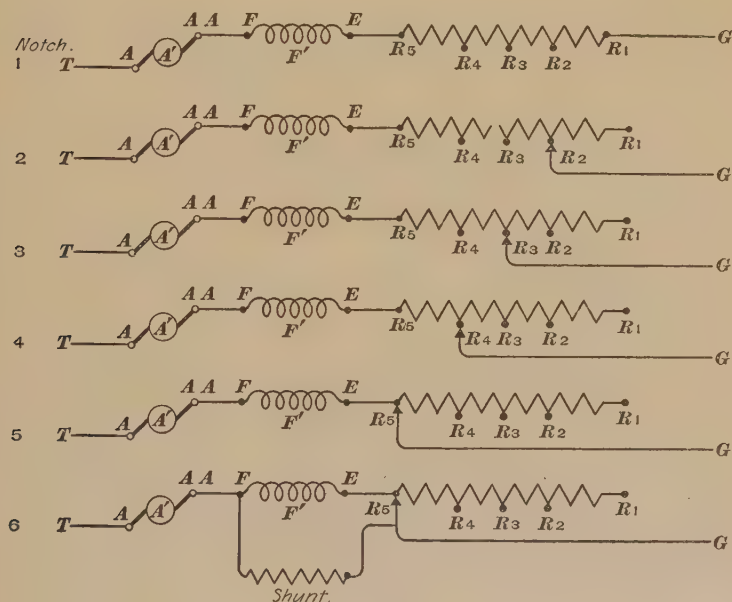


FIG. 27

starting. In most controllers the resistance is placed on the line side of the motors ; the relative position of the motor and the resistance makes no difference so far as the effect of the resistance itself is concerned ; it may sometimes, however, make a difference in regard to the trouble that may arise when an earth occurs on the resistance. If the motor is connected on the line side of the resistance, short-circuit current may flow through the motor. If the resistance is connected on the line side, the motor will be protected.

SERIES-PARALLEL CONTROL

64. **General Description.**—The method of speed control now almost universally used for direct-current traction work is known as the *series-parallel control*. It enables the motors to be run at low speed without the continuous use of resistance, and hence is more economical on low speeds than the simple rheostatic method. The series-parallel control is only applicable to equipments of at least two motors per car. For low speed, the motors are connected in series between the trolley wire and earth, and for high speed, the motors are connected in parallel; hence, this system is known as the **series-parallel control**.

65. If the line pressure is 500 volts and the two motors on a car are connected in series, as shown in Fig. 28, the pressure across each motor will be only 250 volts. Each motor will then

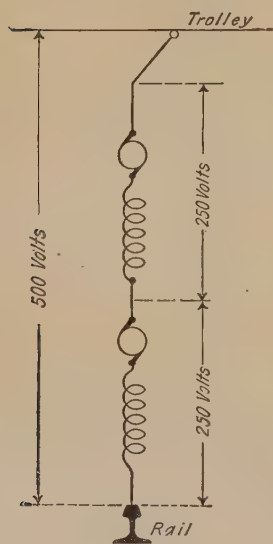


FIG. 28

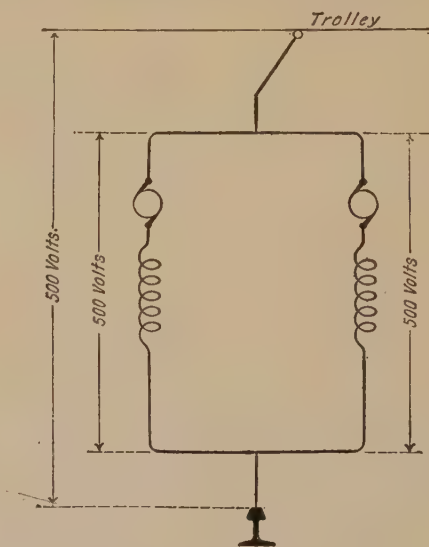


FIG. 29

have to run at only about half its normal speed in order to generate the required back E.M.F., and the motors can run economically at half speed without the use of any resistance.

When the motors are to run at a higher speed, the controller drum is moved round to the *parallel notches* and effects the combinations necessary to change the connections of the motors from series to parallel. When they are in parallel, as shown in Fig. 29, a pressure of 500 volts is applied to each motor and the car runs at full speed. Of course, at starting, it is necessary to include some resistance in circuit with the motors, and when changing from series to parallel, resistance is also cut in to prevent an excessive rush of current and to give a smooth acceleration to the car; but the resistance is cut out as soon as the car gets under way and is not used on the running notches for either high or low speed.

BRITISH THOMSON-HOUSTON K2 CONTROLLER

66. Development and Types.—The General Electric Company of America were among the earliest makers of tramway controllers, their series-parallel controllers being of three types, respectively termed type K, type L, and type B. Controllers designated by the letter K are intended for controlling two or more series motors, and include the feature of shunting or short-circuiting one of the motors when changing from series to parallel. Type L controllers are also intended for two or more series motors, but in changing from series to parallel the power circuit is completely opened for an instant and then closed after the change from series to parallel has been made. Type L controllers are used for large cars equipped with heavy motors. Type B controllers are arranged for magnetic and rheostatic braking, but are in general similar to type L. These various controllers either with or without modification are supplied by the British Thomson-Houston Company.

67. Features of K2 Controllers.—All type K controllers embody many of the features described in connection with the R11 type of controller. The magnetic blow-out is arranged in the same way, and the general mechanical construction is the same, although, of course, the type K is more complicated, because it must control all the connections for two or more motors and

effect the necessary changes of connections from series to parallel. It is also provided with switches, by means of which either motor may be cut out, allowing the car to be operated on the other

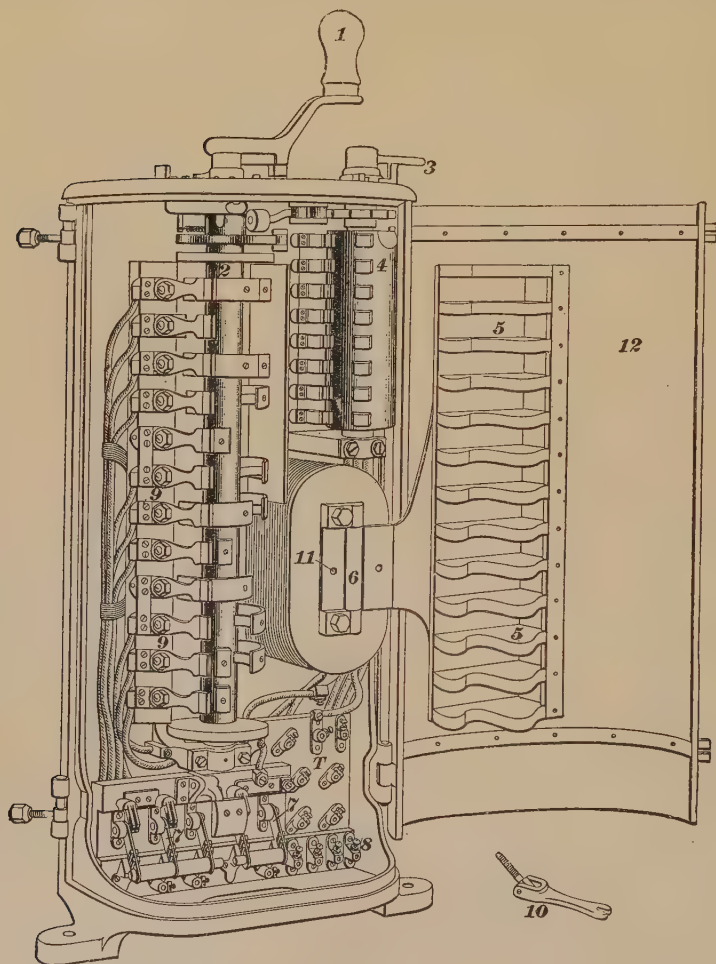


FIG. 30

motor. The K2 controller is designed for use with diverters for obtaining the maximum speed ; that is, both on the last series notch and on the last parallel notch the fields of both motors

are shunted by diverter resistances. The controllers may, however, be used without shunts, if the top speed obtained without them is sufficiently high, and they are frequently run in this way.

The K2 controller is capable of controlling two motors of 40 horsepower or under and has 9 notches. There are 12 combinations or positions on the controller in all, but only 9 of them are marked on the controller top, and the star wheel of the controller is so cut that the handle cannot be made to rest at the passing or changing positions, or anywhere except on a marked notch.

68. Construction of Controller.—Fig. 30 shows a K2 controller with the door opened so that the inside parts can be seen. The operating handle *1* is used to turn the controller or power cylinder *2*, and *3* is the reverse handle for rotating the reverse cylinder *4*. The fingers *9* make contact with the segments of the power cylinder, which are separated by the insulating partitions *5*. These partitions are carried on the movable pole of blow-out magnet *6*. The combined bolt and wrench *10* is used to screw the pole piece of the blow-out magnet to the pole at *11*. The reverse cylinder has no blow-out coil, because its connections cannot be broken while current is flowing. Two cut-out switches *7*, by means of which a disabled motor can be cut out of circuit, are provided. All wires entering the controller are connected to terminals on the *connection board 8*. The terminals on the connection board are joined to the various parts of the controller, as shown for one case by terminal *T* attached to the lead from the blow-out coil. Both the power drum and the reverse drum of this controller are longer and carry more contact segments than those of the rheostatic controller. The interlocking device between the two drums is practically the same on both controllers.

69. A view of the controller cover showing how the notches are indicated is given in Fig. 31. Each of the raised ribs *1, 2, 3*, etc., corresponds to a notch, and the running notches *4, 5, 8*, and *9* are indicated by ribs longer than *1, 2, 3, 6*, and *7*, which represent the resistance notches. Both the main handle *H* and

the reverse handle *K* are shown at the off-position ; the index of the main drum is a small pointer, pointing in the opposite direction to the handle.

The connections to the motors are such that when the reverse handle points ahead the car runs in that direction, and when

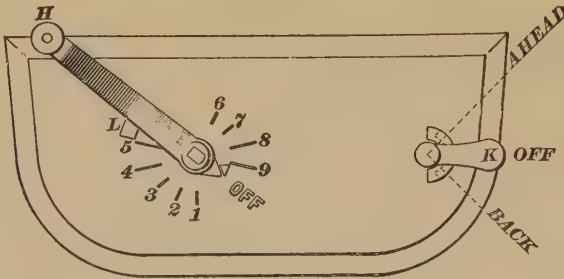


FIG. 31

the handle points back the car runs in the reverse direction ; the direction in which the reverse handle points thus indicates the direction of running.

70. Simplified Connection Diagram.—The various combinations affected by a K2 controller are indicated in Fig. 32. The connections to the motors and resistances for each of the positions of the power drum from 1 to 12 are shown, it being assumed that power is supplied from the point *T* and that the outer circle represents the connection to earth at *G*. In position 1 current flows from *T* through the blow-out coil *M*—all the sections of resistance from *R1* to *R4*—*AA1*—armature 1—*A1*—*F1*—field 1—*E1*—*AA2*—armature 2—*A2*—*F2*—field 2—*E2*—earth at *G*. In position 2 the first section of the resistance is short-circuited, the other connections remaining as before. In position 3 only one section of resistance remains in circuit, and in position 4 all the resistance is cut out, so this position is also a running notch. In position 5 the fields are shunted by the resistances or diverters *S*, so that the speed is greater than on position 4. Position 5 is also a running notch, as there is no resistance in series with the motors. Positions 6, 7, and 8 are transition positions in the change from series to parallel connection of the motors. In position 9 there

are two sections of resistance in series with the motors which are in parallel, and in position 10 there is only one section of resistance remaining in circuit. Positions 11 and 12 are both

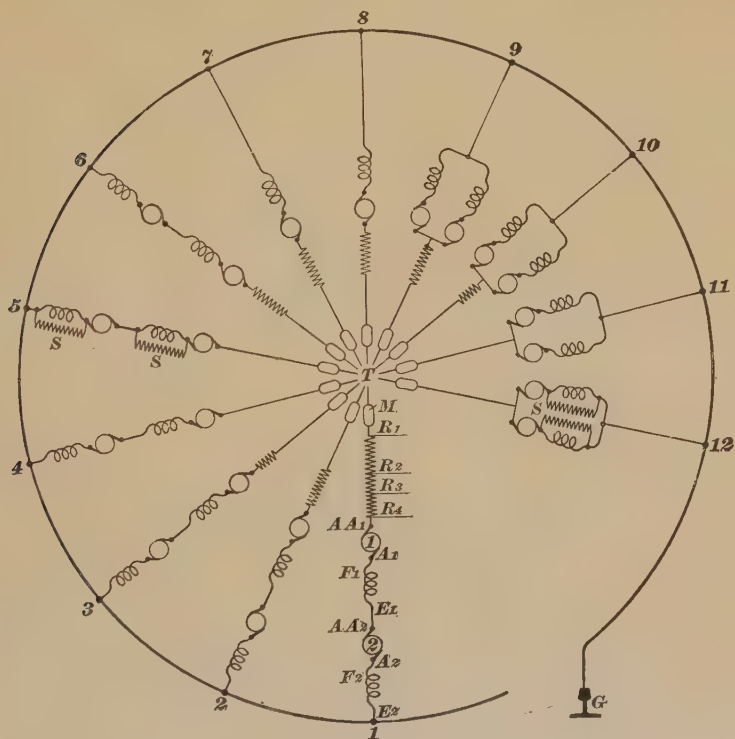


FIG. 32

running notches, as the resistance has all been short-circuited ; in the latter position the fields are shunted.

CAR-WIRING DIAGRAM FOR K2 CONTROLLERS

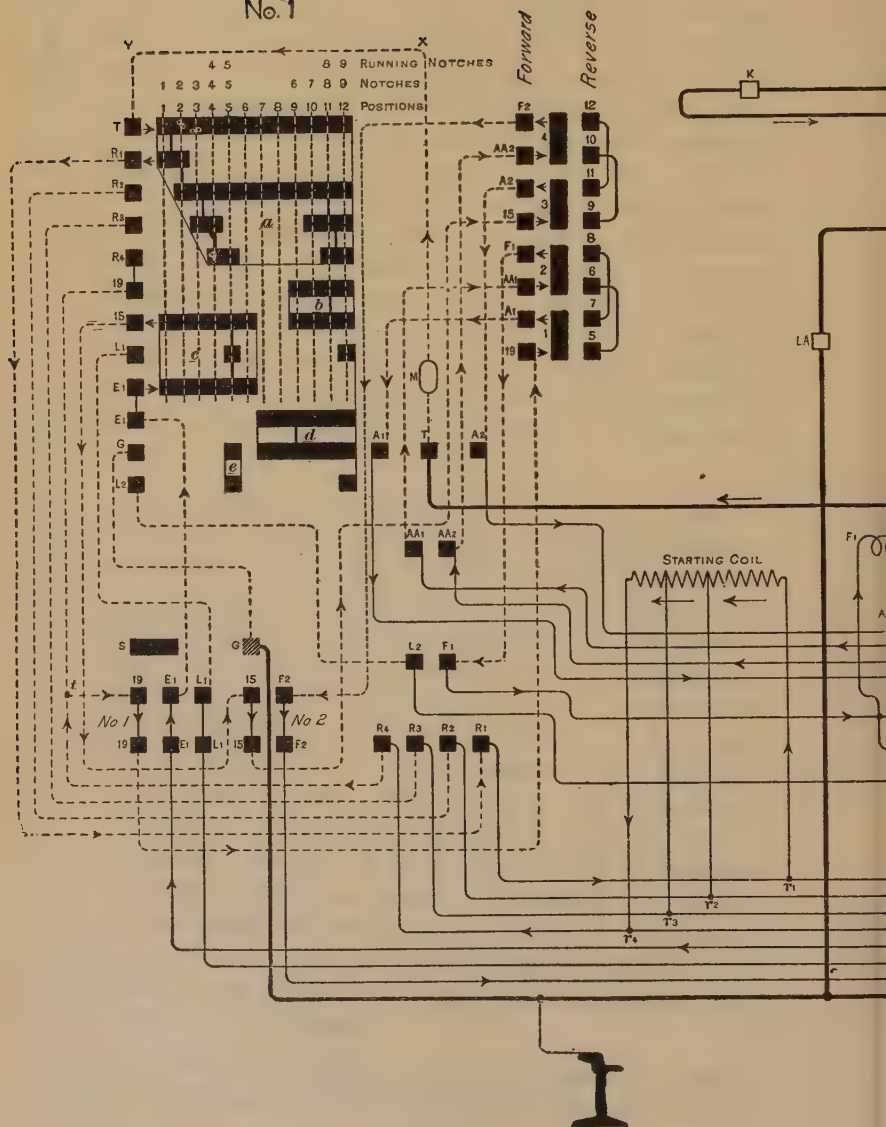
71. Connections to Armatures.—In the diagram of the car wiring for two K2 controllers, Fig. 33, the armature wires are interchanged in the two controllers ; for example, the wire connecting to terminal *AA1* in No. 1 controller connects to terminal *A1* in No. 2 controller. If this precaution is neglected, the car will

move in the direction in which the reverse handle points at one end of the car, but in the opposite direction at the other. Moreover, since the motors are mounted back to back on the truck, that is, with their commutators toward opposite sides of the car, they must run in opposite directions when each is viewed from the commutator end, in order that both the motors may propel the car in the same direction. In the wiring diagram the connections are such that the current flows through both armatures in the same direction, but the direction through No. 2 field is opposite to that through No. 1 field, and No. 2 motor would therefore run in a direction opposite to No. 1 when viewed from the commutator end. The usual method of testing the correctness of the connections is to connect up the motors and switch on the current; if it is found that either or both of the motors tend to drive the car in the opposite direction to that indicated by the reverse handle, the motor or motors at fault can easily be reversed by interchanging the connections to the field terminals.

72. Controller Positions and Notches.—The power drum or cylinder of the K2 controller is made of five castings, which are designated on the diagram, Fig. 33, by the letters *a, b, c, d, e*, and are insulated from one another and from the shaft. The twelve positions of the cylinder are indicated by the vertical dotted lines; only nine of these correspond to notches in the index, or star, wheel, 6, 7, and 8 being transition positions that are passed over quickly. Of the 9 notches, 4, 5, 8, and 9 are running notches, as indicated by the numbers above the development of the power cylinder. On the first running position, notch 4, the two motors are in series and all the resistance is cut out of circuit. On notch 5 the connections are the same as on 4, except that the fields are shunted by shunts *L1* and *L2*. If shunts were not used, the speed on notch 5 would be the same as on 4. On notches 8 and 9 the motors are in parallel, both on line voltage, and as the fields are shunted on notch 9, this gives the highest possible speed.

73. Connections With Motors in Series.—Assuming No. 1 controller to be used, with the reverse switch at the forward

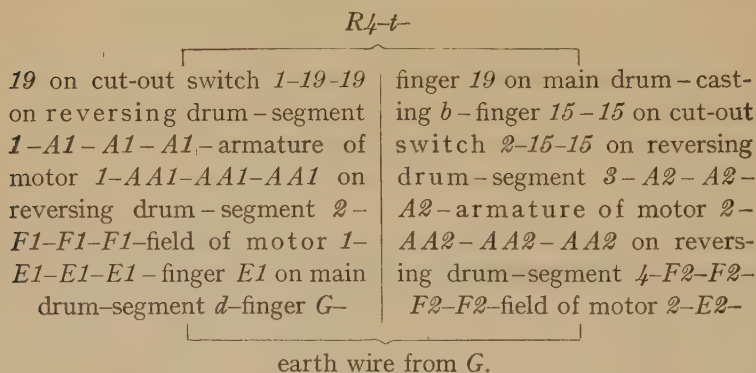
No. 1



position; the path of the current from the trolley wire to the rail, with the controller on the first notch, is shown by the arrowheads on the conductors in Fig. 33, and is as follows, beginning at the trolley terminal *T* on the connection board of No. 1 controller: *T*—blow-out coil *M*—*X*—*Y*—finger *T*—casting *a*—finger *R1*—terminal *R1*—*r1*—whole of starting coil to *r4*—terminal *R4*—*t*—19 on cut-out switch—19—finger 19 on reverse switch—segment 1—finger *A1*—terminal *A1*—brush *A1* on motor No. 1—No. 1 armature—brush *AA1*—terminal *AA1*—finger *AA1* on reverse switch—segment 2—finger *F1*—terminal *F1*—field terminal *F1*—field to *E1*—terminal *E1* on No. 1 cut-out switch—*E1*—fingers *E1* *E1* on controller—casting *c*—finger 15—terminal 15 on No. 2 cut-out switch—15—finger 15 on reverse switch—segment 3—finger *A2*—terminal *A2*—brush *A2*—No. 2 armature—brush *AA2*—terminal *AA2*—finger *AA2* on reverse switch—segment 4—finger *F2*—terminal *F2*—*F2*—field terminal *F2*—*E2*—earth or rail. Both motors are in series, therefore, with all the starting resistance. As notches 2 and 3 are passed, the first two resistance sections are successively short-circuited when fingers *R2* and *R3* make contact with the casting *a*, and the fourth notch is the series running notch to be used when low speed is desired. On the fifth notch, finger *L1* makes contact with *c*, and *L2* and *G* with *e*, thus placing the shunts *L1* and *L2* in parallel with the motor fields. The sixth position is one of transition and gives the same combination as the second position, part of the resistance being temporarily cut back into the circuit preparatory to breaking the circuit of motor No. 2. On positions 7 and 8, No. 2 motor is dropped out of circuit momentarily by fingers *E1* and 15 leaving casting *c*; at the same instant a connection is made between *E1* and earth at *G* by fingers *E1* and *G* making contact with segments *d*, thus maintaining the circuit through the No. 1 motor, which is thus connected between line and earth in series with two sections of the starting resistance.

74. Connections With Motors in Parallel.—On position 9 (notch 6), Fig. 33, No. 2 motor is put into circuit in parallel with No. 1, two sections of the resistance still remaining in series, as on positions 6, 7, and 8. The paths of the current through

the two motors on notch 6, therefore, starting from terminal *K4*, are :



On notch 7, the second section of starting resistance is short-circuited, and on notch 8 all the resistance is short-circuited ; the motors, however, run with full field strength. On the last notch, the fields are shunted and the motors run at full speed.

75. Motor Cut-Out Switches.—The two motor cut-out switches are represented on Fig. 33 by black squares below the diagram of the power drum and are marked No. 1 and No. 2. These two switches are two-way, and when both motors are in use, both switches should be closed in the lower contacts as indicated by the connecting lines. When No. 1 switch is closed in the top contacts, terminals 19 and E1 are connected together through the connector S, and assuming that the controller is on the first notch, the path of the current beginning at point *t* is : *t-19-S-E1-E1-E1-c-15-15-15-15-3-A2-A2*, etc. No. 1 motor is cut out and the current flows through No. 2 motor to earth. If No. 2 switch is closed in the top contacts, switch No. 1 being down, the current on reaching terminal 15 on No. 2 switch goes directly to the earth terminal G and No. 2 motor is cut out. When either of these switches is used, it brings into action a device which interlocks with a collar on the power-cylinder shaft to prevent the cylinder from being moved beyond the last series position. Thus, if one motor is disabled and short-circuited it cannot be connected in parallel with a good motor, which would then also be short-circuited.

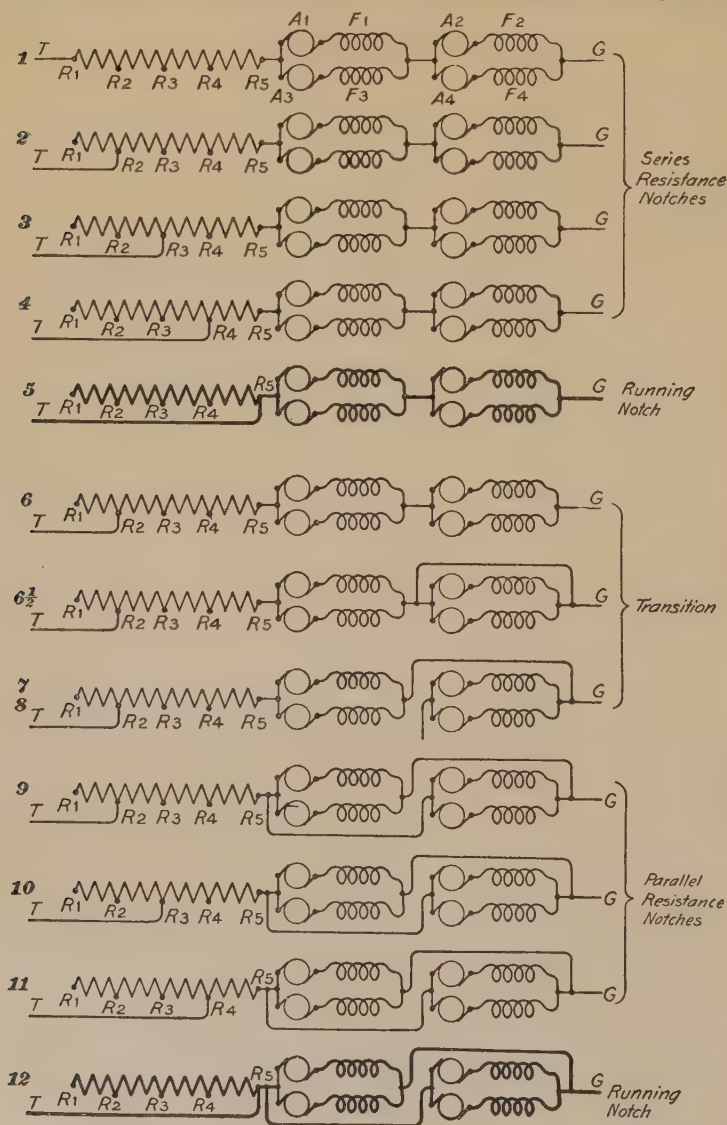
76. Lightning-Arrester Circuit.—In the wiring diagram, Fig. 33, for two K2 controllers there are two alternative circuits from the trolley wire to the rail: the main circuit through the motors and a lightning-arrester circuit through the lightning arrester *LA*. The latter usually includes an air gap, or series of small air gaps, so that under ordinary conditions no current flows through the lightning-arrester circuit. If the trolley wire becomes charged at high pressure, however, due to lightning or other abnormal condition, the current passes to earth across the air gap of the arrester, the circuit being as follows: Trolley wheel *W*—canopy switches *K*, *K*, one at each end of the car—fuse or circuit-breaker *FB*—lightning arrester *LA*—earth wire—rail. A **choke coil**, termed also a **choking**, or **kicking**, coil, is inserted in the main motor circuit between the fuse *FB* and the connection *O* leading to the trolley terminals *T* of the controllers. The coil is simply a highly inductive coil, through which the ordinary direct current flows without check, but which chokes back the alternating or pulsating current of a lightning discharge and protects the motors by compelling the discharge to take the direct path to earth through the arrester.

BRITISH THOMSON-HOUSTON K12 CONTROLLER

77. Method of Connecting Four Motors.—The usual method of controlling a four-motor equipment is permanently to connect the motors in pairs in parallel and then to treat the two pairs as if they were single motors, operating them by the series-parallel method, as in the case of a regular two-motor equipment. Fig. 34 shows the various combinations effected by the K12 controller, which provides four series resistance notches and one running notch with the motors in series. No diverter resistances are used to give extra-high speed, and the car should be operated only on one running notch with either the series or parallel connection.

The resistance tappings are lettered *R1* to *R5*, the position of the connection from the trolley *T* indicating the number of resistance sections included at any position of the controller drum from 1 to 12. For example, in position 1 the circuit is as follows: *T*—*R1* to *R5*— $\begin{matrix} \diagup A1-F1 \\ \diagdown A3-F3 \end{matrix}$ — $\begin{matrix} \diagup A2-F2 \\ \diagdown A4-F4 \end{matrix}$ —*G*.

In the transition from series to parallel running, the pair of

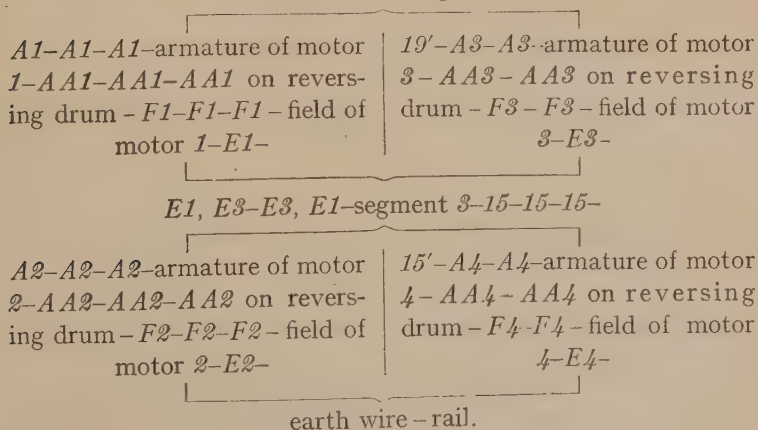


motors nearest the earth connection are first short-circuited, as

indicated at position 6¹, and then open-circuited, as shown on the diagram at positions 7 and 8 before making the parallel connection indicated at position 9.

CAR-WIRING DIAGRAM FOR K12 CONTROLLERS

78. Connections on Series Notches.—A diagram of the wiring of a car equipped with two K12 controllers and four motors is shown in Fig. 35. The power cylinder has five resistance segments, but no diverter segment. The reversing drum is provided with a double row of contact fingers, so that the current in all four armatures can be reversed when the car is to be run in the reverse direction. When the car runs forward, reverse-drum fingers *b* are in contact with the segments *a* and fingers *d* are in contact with segments *c*. When the car runs back, fingers *b* make contact with segments *c* and fingers *d* with segments *e*, thus reversing the current in all four armatures. The leads *E2* and *E4* from the No. 2 and No. 4 motor fields are permanently connected to the earth or ground wire. The main trolley wire is connected to finger *T* on the power cylinder through the blow-out coil, as shown. The path of the current when the right-hand controller is on the first notch is indicated by the arrows and is as follows, starting from finger *T* at the power cylinder: *T-R1-R1-R1*—through all resistance—*R5-R5-19-19* on reversing drum—



The resistance sections are successively cut out until the motors are in full series on notch 5.

The other combinations are indicated by Fig. 34, and may be traced out on the diagram, Fig. 35, in a similar way. The cut-out switches are arranged to cut out the motors in pairs; for example, if No. 1 motor breaks down and the cut-out switch lettered *19 E1 E3* is closed in the top contacts, motors No. 1 and No. 3 are cut out.

BRITISH THOMSON-HOUSTON B18 CONTROLLER

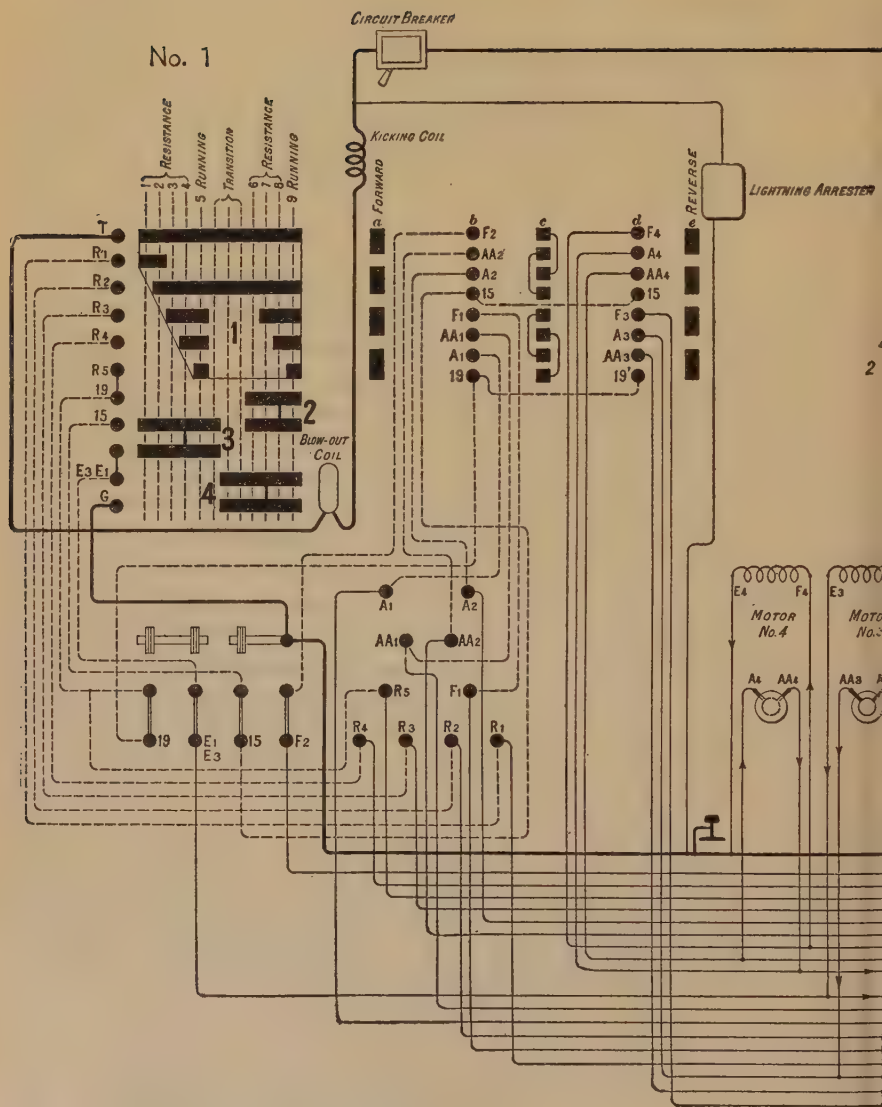
79. General Features.—The B18 controller, extensively used on modern British tramway systems, is a modification of the K-type controller, and is arranged for series-parallel control with the addition of notches for either rheostatic or magnetic brakes. It has four series notches, four parallel notches, and six braking notches, the running notches being No. 4, with the motors in series, and No. 8, with the motors in parallel. Rheostatic braking is effected by connecting the motors as series generators, in parallel with one another and in series with the starting resistance. On the first brake notch the whole of the resistance is connected in series with the motors, and on succeeding notches the resistance is cut out step by step, with increasing braking effect, until the motors are short-circuited. If desired, magnetic brakes operated by the current supplied by the motors may be used. In this case the braking effect is due both to the magnetic brakes and to the generator action of the motors.

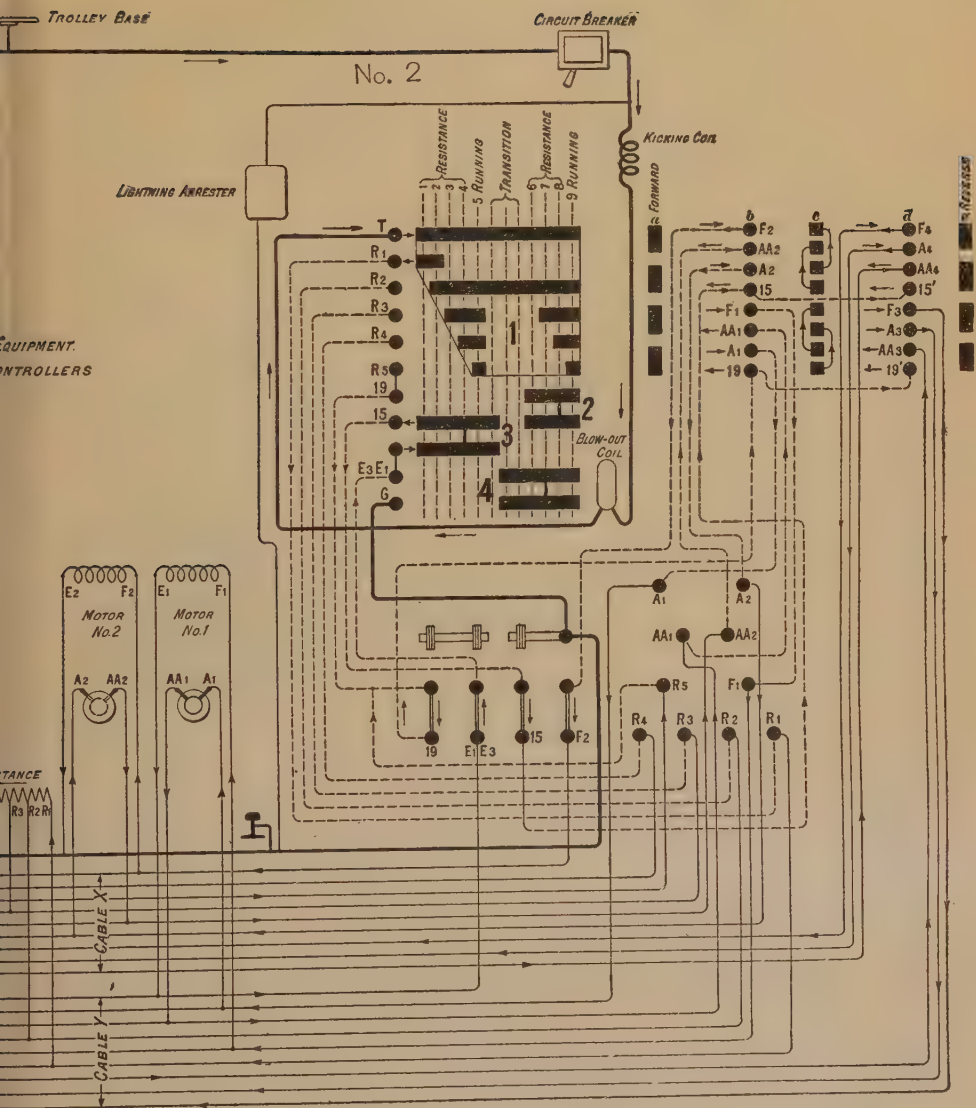
80. Blow-Out Coil.—The blow-out coil is provided with two distinct windings, one of which is in circuit on the power notches and the other only on the brake notches. To facilitate tracing the circuits, the terminals of the two windings are marked similarly to the controller fingers with which they are connected.

CAR-WIRING DIAGRAM FOR B18 CONTROLLERS

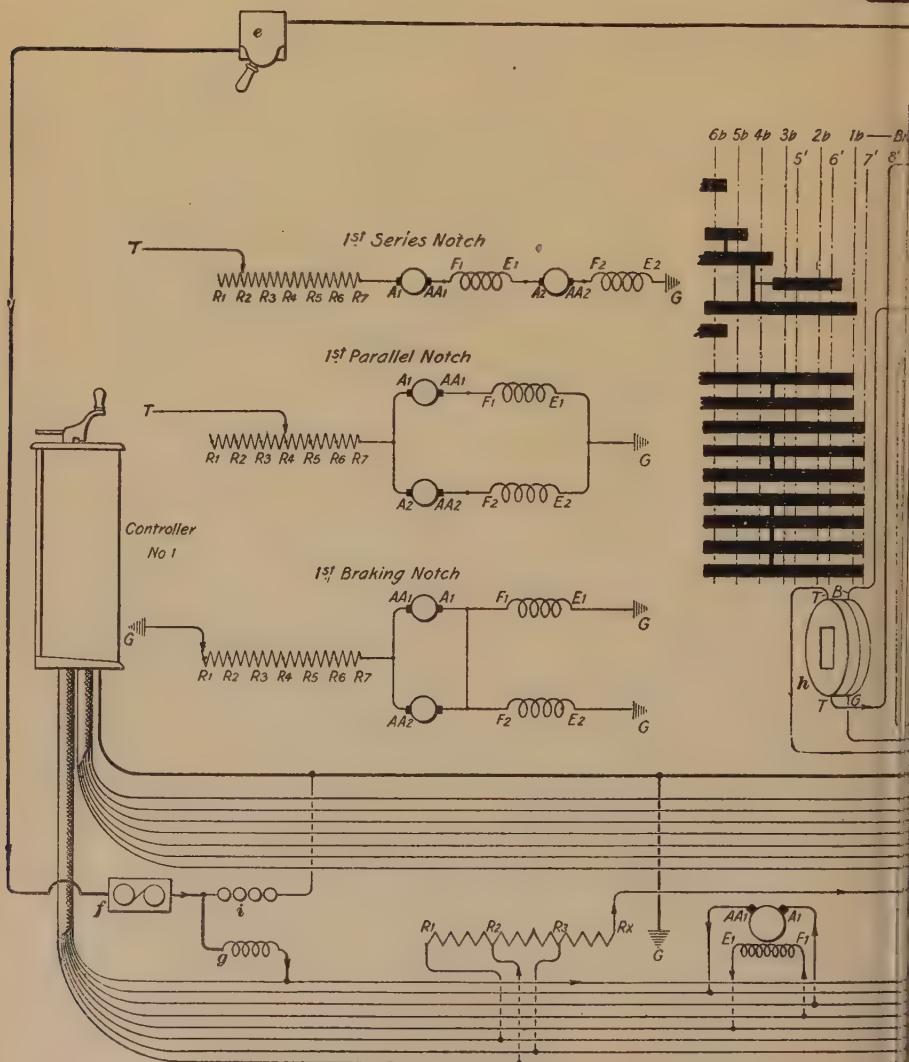
81. Controller Positions.—A diagram of the wiring of a car fitted with two B18 controllers and two motors is shown in Fig. 36. There are two sets of contact fingers which bear against

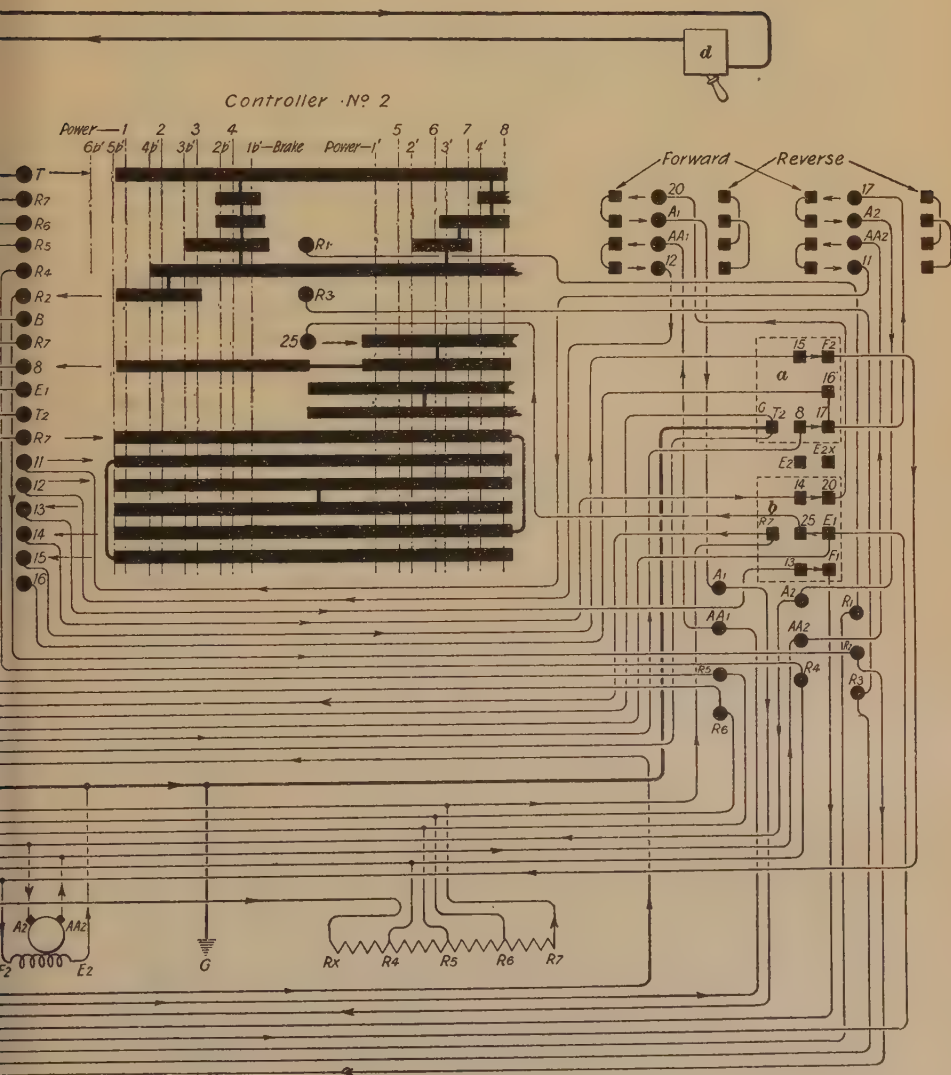
No. 1





WIRING FOR CAR WITH B 18 CONTROLLERS AND TWO MOTORS.





the segments of the controller drum. The positions of the main group of fingers on the power and braking notches are indicated by the numbers 1 to 8 and 1*b* to 6*b*, respectively. The corresponding positions of the secondary group of fingers *R*1, *R*3, and 25 are indicated by numbers 1' to 8' and 1*b*' to 6*b*'. In studying the connections corresponding to the various controller positions, the whole power drum with both sets of segments must be assumed to move under the two sets of contact fingers. A number of the segments are continuous from one set to the other. These segments are the ones which make contact with the fingers *R*7, *R*4, *E*1, and *T*2, and are shown broken at the ends.

Moving the drum to the left gives the connections for the power notches and to the right the connections for the braking notches. The connections for the first series, first parallel, and first braking notches are shown in simplified form in the small diagrams.

82. Cut-Out Switches.—Two motor cut-out switches *a* and *b*, Fig. 36, are provided on the B18 controller connection board, so that either motor can be cut out of service without interfering with the working of the other motor. Both switches are normally closed in the right-hand contacts, but when switch *a* is thrown over and closed to the left side, terminal 8 is connected to terminal *T*2 and *G* and to earth, and motor No. 2 is cut out. When switch *a* remains closed on the right-hand side, and switch *b* is thrown over and closed on the left-hand side, terminal *R*7 is connected to terminal 25 and thence through motor No. 2 to earth, motor No. 1 being cut out of circuit.

83. Connections on Series Notches.—The main circuit from the trolley wire to the controller, Fig. 36, is as follows: Trolley wheel *c*—main motor switch *d*—automatic circuit-breaker *e*—fuse *f*—kicking coil *g*—blow-out coil *h* to terminal *T*—trolley finger *T* on main power drum. The lightning arrester *i* provides a path to earth if the pressure on the line becomes excessive through any cause.

The path of the current through the controller on the first series notch, with the reversing drum in the forward position,

is as follows: Trolley finger *T* - drum contact - finger *R2* - terminal *R2* - through rheostat to terminal *R7* - finger *R7* - main drum to finger *14* - cut-out switch terminal *14* - terminal *20* - finger *20* on reversing drum - finger *A1* - terminal *A1* - armature terminal *A1* - armature of motor *1* - *AA1* - controller terminal *AA1* - finger *AA1* - finger *12* on reversing drum - finger *12* on main drum - finger *13* - terminal *13* on cut-out switch - *F1* - *F1* - field of motor *1* - terminal *E1* - cut-out switch terminal *E1* - *25* - finger *25* - drum contacts - finger *8* - cut-out switch terminal *8* - terminal *17* - finger *17* on reversing drum - finger *A2* - terminal *A2* - armature terminal *A2* - armature of motor *2* - *AA2* - controller terminal *AA2* - finger *AA2* - finger *11* - finger *11* on main drum - finger *15* - cut-out switch terminal *15* - terminal *F2* - *F2* - field of motor *2* - *E2* - earth at *G*. On the second notch the first section of resistance is cut out. The remaining sections of resistance are cut out in two steps, on the third and fourth notches, giving the full line pressure across the motors in series.

84. Connections on Parallel Notches.—On notch 5, Fig. 36, the motors are connected in parallel with resistance in series. The path of the current, with the reversing drum in the forward position, is as follows: Finger *T* - finger *R4* - terminal *R4* - resistance *R4* - *R7* - terminal *R7* -

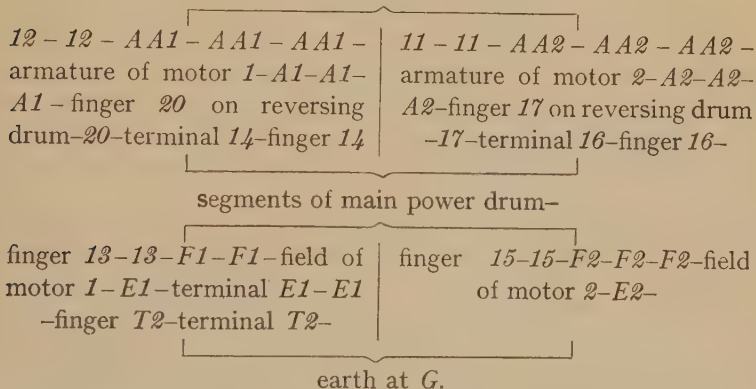
finger *R7* - finger *14* - terminal *14* on cut-out switch - *20* - finger *20* on reversing drum - finger *A1* - terminal *A1* - *A1* - armature of motor *1* - *AA1* - *AA1* - finger *AA1* - *12* - *12* - *13* - *13* - *F1* - *F1* - field of motor *1* - *E1* - *E1* - finger *E1* - *T2* - *T2* -

finger *R7* - finger *8* - terminal *8* on cut-out switch - *17* - finger *17* on reversing drum - finger *A2* - terminal *A2* - *A2* - armature of motor *2* - *AA2* - *AA2* - finger *AA2* - *11* - *11* - *15* - *15* - *F2* - *F2* - field of motor *2* - *E2* -

earth at *G*.

On notches 6, 7, and 8 resistance is successively cut out, the last notch giving the motors full parallel connection across the line with all resistance cut out of circuit.

85. Connections on Brake Notches.—In order to operate the electric brake the controller handle is turned backwards past the off-position. On the first brake position fingers *R1*, *R3*, and *25* are in the position indicated by the dotted line *1b'*, and the main fingers are in the position indicated by dotted line *1b*. The path of the current through the motors, which are in parallel, is as follows: Earth at *G* - *T2* - blow-out coil *h* - *B* - *B* - finger *R1* - *R1* - resistance *R1* to *R7* - *R7* -



In tracing the brake circuits, it should be noted that the relative connections of the fields and armatures have been reversed so that the motors may act as generators. On the second brake notch *2b* finger *R2* makes contact with a segment and one section of the resistance is cut out. On the third notch, finger *R3* takes a position as indicated by *3b'*, and a second section of resistance is cut out of the motor circuit. The resistance is thus successively cut out until on notch *6b* the motors are short-circuited.

WESTINGHOUSE T1 CONTROLLER

86. General Features.—The T1 controller is designed for controlling two motors on tramway systems with the ordinary earth return, and combines series-parallel features with rheostatic or magnetic braking, as desired. The controller has four series, four parallel, and seven braking notches; the large number of braking notches gives a very smooth braking effect. The

reversing drum is carried by a loose sleeve on the upper part of the power-drum shaft. The lower part of the shaft is square and the power-drum segments are rigidly attached thereto.

87. Interlocking Devices.—The interlocking and notching gear of the two drums is shown in Fig. 37. The cover-plate of the controller has been removed, but the power handle *a* and reversing handle *b* are shown in place, both at the off-position. The star wheel *c* of the power drum has four series notches *d*, four parallel notches *e*, and seven braking notches *f*. The stops *g* and *h* carried on the star wheel and the controller cover, respectively, prevent the main drum from being rotated too far in

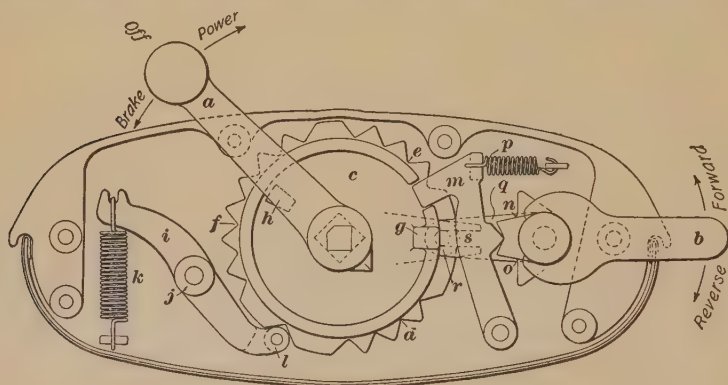


FIG. 37

either direction. The lever *i*, pivoted at *j*, and actuated by the spring *k*, prevents the star wheel from remaining in any but the definite notch positions by the roller *l* engaging with the star-wheel notches. Normally, when the reverse handle *b* is in the off-position the power drum is prevented from moving by the hook *m* engaging with a notch in the star wheel *c*. When the reversing handle is moved to the forward or reverse position, deep V notches *n, o* in a segmental casting at the end of the handle of the reverse drum allow the hook *m* to be withdrawn from the notch in the main star wheel by the spring *p*. A lever arm *q*, which moves below the star wheel *c* and hook *m*, is also rotated by the reverse handle. The arm *q* carries a roller *r*, shown dotted, which moves a fork *s* attached to the loose sleeve

of the reversing drum on the main shaft, and thus turns the reversing drum through a sufficient angle to make the necessary connections.

CAR-WIRING DIAGRAM FOR T1 CONTROLLERS

88. Notches and Cut-Outs.—The wiring diagram of a car provided with two T1 controllers and two motors is given in Fig. 38. There are two sets of fingers, *A* and *B*, and the respective power positions of these are indicated by the dotted vertical lines numbered 1 to 8 and 1' to 8'. The positions for the fingers in group *A* on the brake notches are marked 1*b* to 7*b*, and the positions for the fingers in group *B* are numbered 1*b*' to 7*b*'. No connection board is provided, the wires being connected directly to the respective contact fingers. To cut out motor No. 1, fingers 2 and *F*1 are raised, and similarly motor No. 2 may be cut out by raising fingers 4 and *F*2.

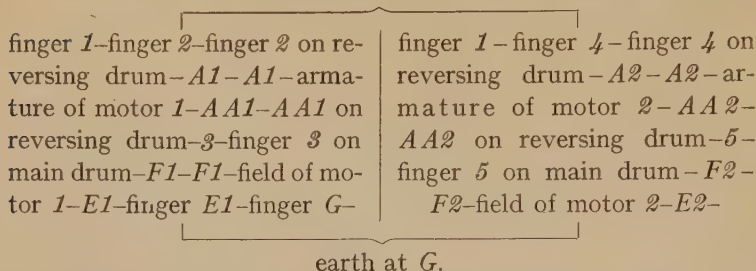
Key diagrams of the connections on the first series, first parallel, and first braking notches are shown in the lower right-hand corner of the car-wiring diagram.

89. Connections on Series Notches.—If the reversing handle of controller No. 1, Fig. 38, is placed in the forward position, and the power handle is in the first position, the path of the current is as follows: Trolley tapping *T*—finger *T*—finger *R*1—resistance *R*1 to *R*7—terminal *R*7—blow-out coils *a* and *b*—finger 1—finger 2—finger 2 on reversing drum—finger *A*1—*A*1—armature of motor 1—*A**A*1—finger *A**A*1 on reversing drum—3—finger 3 on main drum—*F*1—*F*1—field of motor 1—*E*1—finger *E*1—4—finger 4 on reversing drum—*A*2—*A*2—armature of motor 2—*A**A*2—finger *A**A*2 on reversing drum—5—finger 5 on main drum—*F*2—*F*2—field of motor 2—*E*2—earth at *G*.

On position 2 the resistance sections between *R*1 and *R*3 are short-circuited, and on position 3 all resistance sections between *R*1 and *R*5 are short-circuited. On position or notch 4 the motors are in series with all the starting resistance cut out.

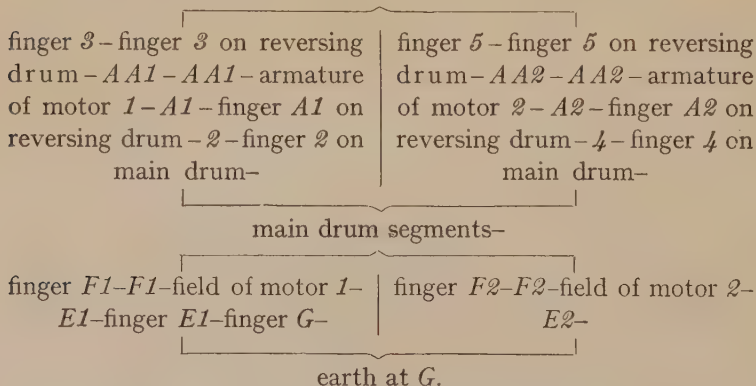
90. Connections on Parallel Notches.—The motors are connected in parallel with part of the resistance in series when the controller drum is in position 5, Fig. 38. The path of the

current is as follows: Trolley tapping T -finger T -finger $R4$ -resistance $R4$ to $R7$ -terminal $R7$ -blow-out coils a and b -

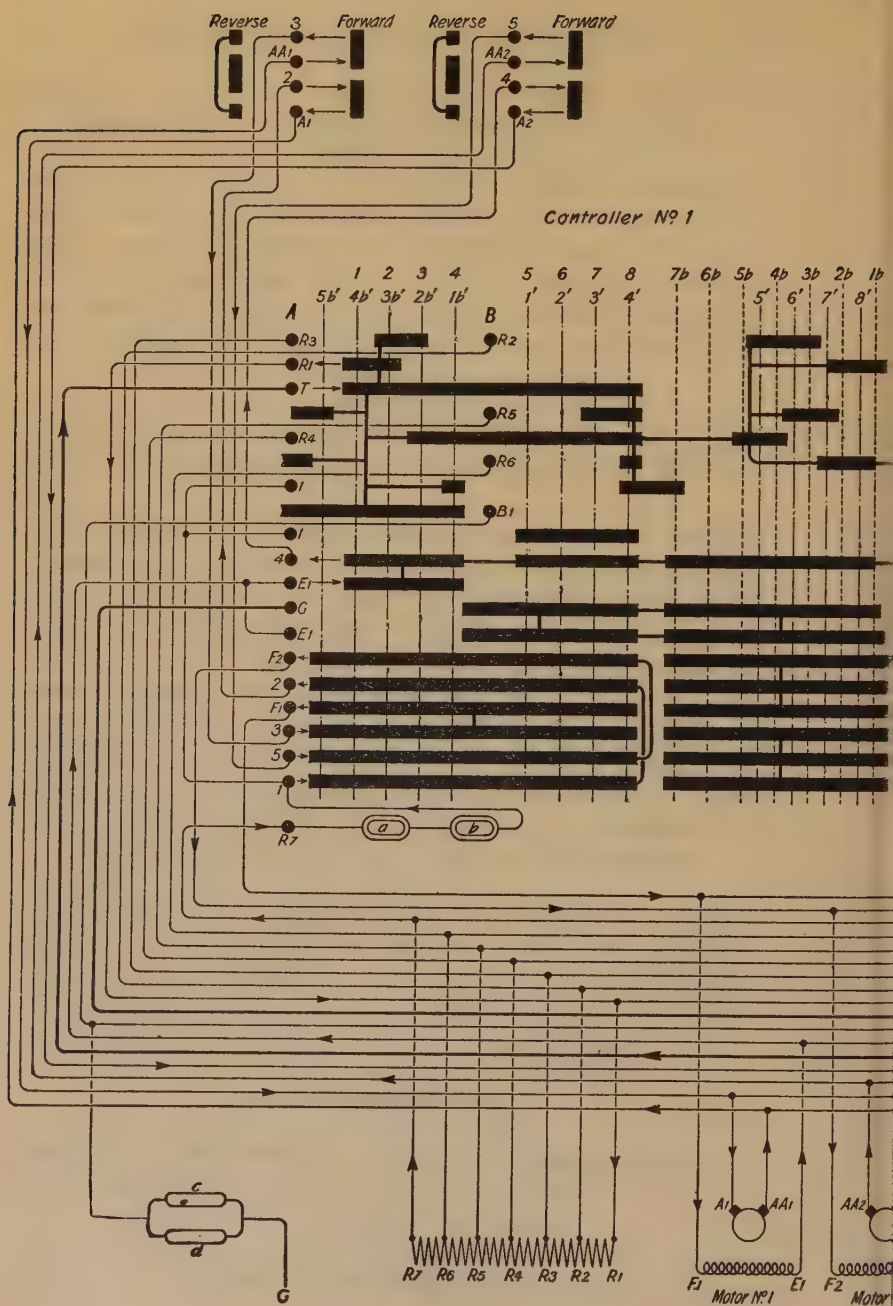


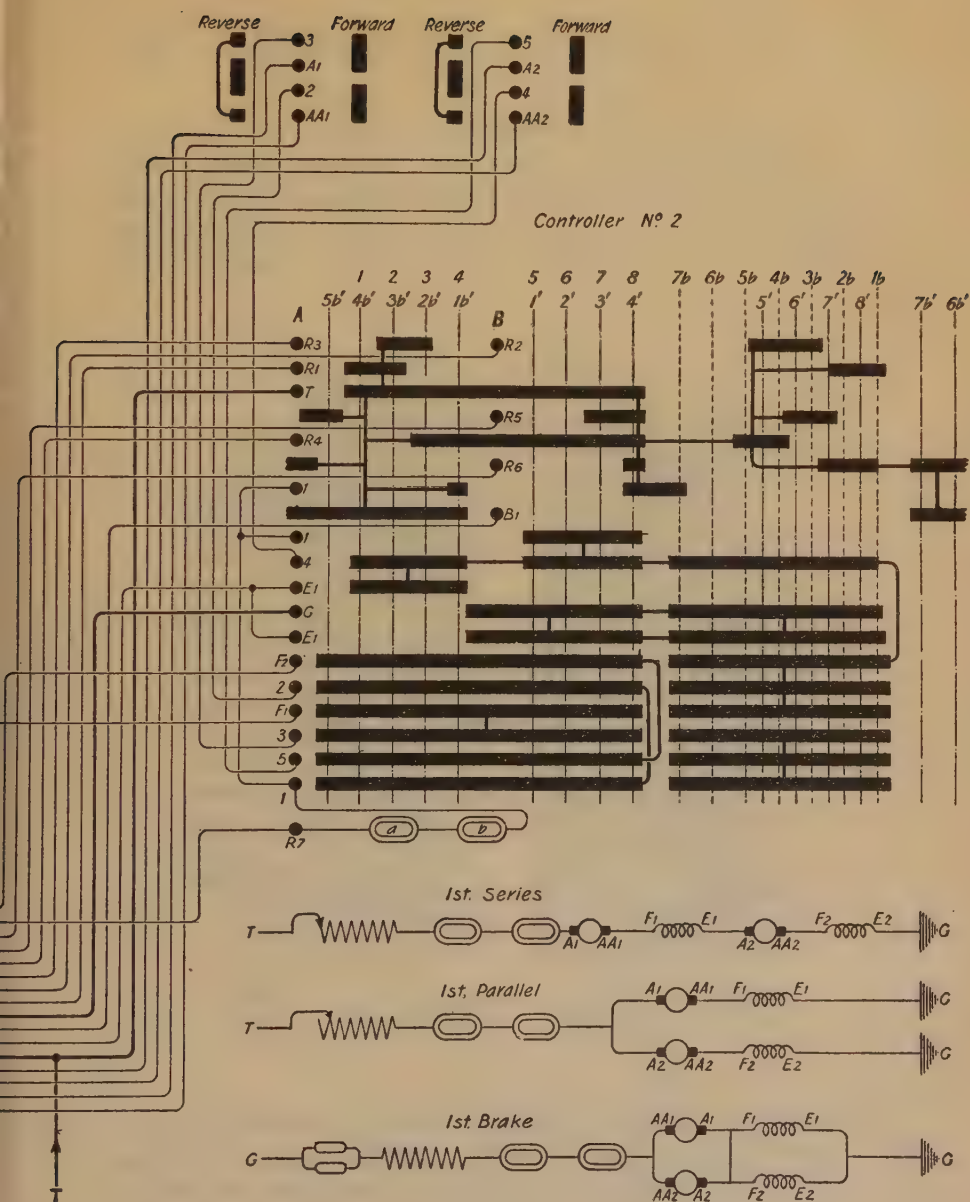
On the other parallel positions the resistance is successively short-circuited until the motors are running in full parallel.

91. Connections on Brake Notches.—The operation of braking by means of the controller, when magnetic brakes are provided on the car, consists in reversing the connections to the motor armatures and in switching the two motors in parallel with each other and in series with the starting resistance and magnetic brakes. On the first braking notch the group of fingers A occupies the position $1b$, Fig. 38, and group B occupies position $1b'$. The path of the current when No. 1 controller is in use is as follows: Earth at G -magnetic brakes c and d -finger $B1$ -main drum segments-finger $R1$ -resistance $R1$ to $R7$ -terminal $R7$ -blow-out coils a and b -finger 1-main drum segments-



The resistance is then cut out in successive steps.





WIRING FOR CAR WITH
T1 CONTROLLERS AND TWO MOTORS

DICK-KERR CONTROLLER

92. **Special Features.**—The Dick-Kerr metallic-shield blow-out controller is largely used for traction work in the British Isles, and it is of special interest on account of the modification of the magnetic blow-out principle adopted in it. Instead of

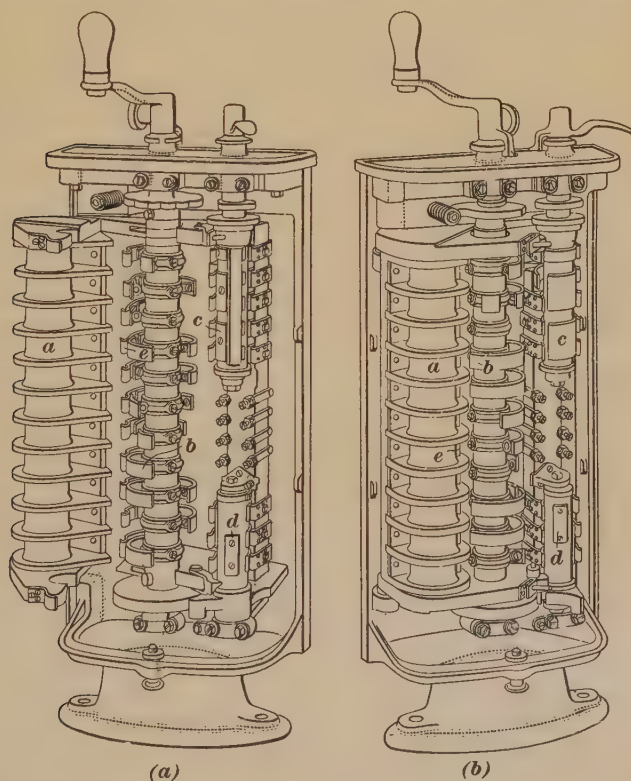


FIG. 39

the usual blow-out coil or coils, which produce a horizontal magnetic field in the neighbourhood of the contacts and tend to blow any arc formed against the insulating partitions, a long solenoid coil *a*, Fig. 39, is placed close to the power cylinder *b* and produces a vertical magnetic field for blowing out the arc. Since the field is vertical, and the direction of current on

breaking circuit between the contact fingers and segments is horizontal, the tendency will be to make the arc travel outwards horizontally from the point of the break in the circuit, until the arc is broken.

In view (a) the controller is shown with the solenoid and insulating partitions thrown back ; in view (b) the parts are in their normal closed position. The reversing cylinder *c*, and a brake cylinder *d*, carrying separate contacts for reversing the armature connections of the motors when braking, are not provided with any blow-out devices, since the connections are not opened when the current is flowing. The contact fingers for the power drum are shown at *e*.

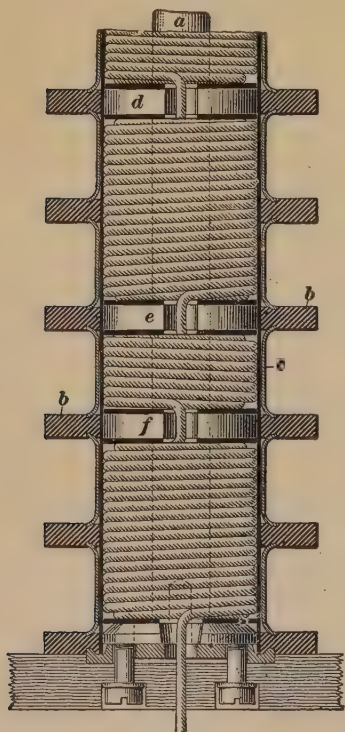


FIG. 40

93. Blow-Out Solenoid.—A vertical section of the blow-out solenoid is shown in Fig. 40. It consists of a coil of insulated wire wound on an iron core *a*. Insulating partitions *b* fit between adjacent fingers and segments of the controller, and between the partitions the solenoid is protected by cylindrical copper shields *c*. The winding is continuous from top to bottom of the solenoid and it carries the full trolley current ; the blow-out effect is thus proportional to the strength of the current which is to be broken. Since the current passes between the fingers and contact segments in opposite directions, according to whether the current is entering or leaving the drum, the magnetic fields set

up for each pair of contacts must be in the proper direction to drive the arc outwards. This condition is secured by winding

different sections of the solenoid coil in opposite directions; consequent magnetic poles are therefore induced at *d*, *e*, and *f*, etc., and the field between the insulating partitions is given the proper direction for each group of contacts.

94. Action of Blow-Out.—The operation of blowing out an arc formed between a finger and a contact segment is shown diagrammatically in Fig. 41. The solenoid is here shown in

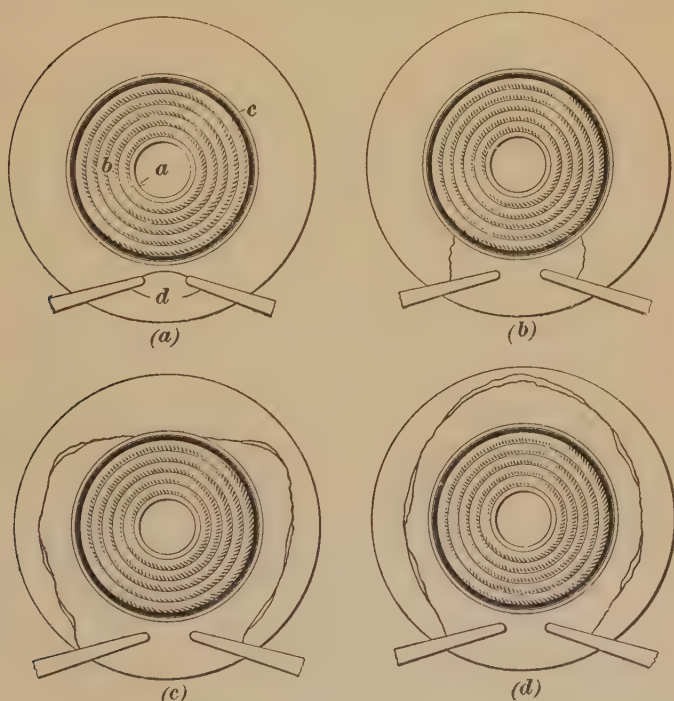


FIG. 41

section, where *a* is the iron core, *b* the winding, *c* the external copper shield, and *d* represents the tips of the finger and contact segment between which the arc is formed. As soon as the arc is formed, as shown in view (a), it commences to travel in the magnetic field outwards from the contact tips and toward the copper shield of the solenoid. In (b) the arc has reached the copper shield, and has divided, the copper shield carrying the

current as the arc lengthens. If the arc has not already been ruptured by the time it reaches the remote side of the solenoid, as shown in (c), it leaves the copper shield and continues to lengthen in the air, as shown in (d), until it does break. The whole action is in practice extremely rapid, and the arc sweeps across the copper shield and is extinguished so rapidly that the surface of the shield is uninjured.

REGENERATIVE CONTROL

USE OF SHUNT-WOUND TRACTION MOTORS

95. Principle of Regeneration.—The energy expended in speeding up a tramcar fitted with series motors is all absorbed by the brakes and dissipated as heat when the car is stopped. The only electrical methods of braking which are available with series-wound motors are the rheostatic- and magnetic-braking systems ; series motors cannot be made to return current to the line. Consider a car fitted with series motors descending an incline. As the speed of the car increases, the back E.M.F. of each motor increases and the current in the armature decreases, with the result that the field is weakened more and more as the speed of the car continues to rise. Since the back E.M.F. never becomes equal to the line P.D., the direction of the current never reverses and the car is not retarded by the motors.

96. If a tramcar fitted with shunt motors proceeds down-hill, the current in the armature gradually decreases, but there is no change in the field current, which remains constant. The current in the armature will continue to diminish as the speed increases, until the back E.M.F. of the motor exceeds the E.M.F. of the trolley wire, whereupon the current in the armature will reverse and the motor will run as a generator driven by the car, in parallel with the power-station generators, and will return current to the line. The work done by the car in supplying current to the line holds the car in check so that it cannot run away. If the shunt field is strengthened, the amount of current

returned to the line is increased, and results in an increased braking effect on the motors and car. The Raworth system is practically the only system of regenerative control which has been commercially successful in operation on British tramway lines, and the description which follows is based on the Raworth system.

97. Practical Results of Regenerative Working.—An important advantage in the use of regenerative control over the ordinary systems of series-parallel control is that of economy of energy. Instead of wasting all the kinetic energy stored in a moving car, by applying mechanical brakes, the regenerative control enables a portion of the energy to be saved by returning it to the trolley wire and assisting to drive other cars on the line. Compared with the ordinary series-parallel control using series motors, it is claimed that the regenerative system uses from 5 to 6 per cent. less energy when running under service conditions on level roads, and up to 30 per cent. less in hilly districts where the cars can return current to the line during long runs down-hill. Some economy results also in connection with the wear of the mechanical brake blocks on the car, since as much of the braking as possible is done electrically, and the mechanical brake blocks do not wear away and require renewal as frequently as with the ordinary system. As current flows in the motors during the whole time that the car is being driven or current is being supplied to the line, the motors used on the car must be of such size as will ensure that the heating of the motors is kept within moderate limits.

98. Series-Parallel Control of Shunt Motors.—In the Raworth system the motors are provided with series windings, across the terminals of which diverter resistances are connected, this winding coming into use on the parallel notches of the controller to give increased torque when the car is running at high speed. The Raworth controller is also arranged so that the circuit is broken during the transition from series to parallel, or vice versa, before any resistance is inserted in the armature circuits of the motors. In accelerating the car, this arrangement is of advantage, as the motors continue to run at the proper speed to drive the

car until the moment of breaking the circuit. In this way the back E.M.F. of each motor does not drop, and the difference of potential between the contact fingers and the segments of the controller drum is so small that there is practically no sparking. In switching from parallel to series, the circuit is broken before resistance is inserted in order to prevent sparking, which might otherwise occur if the speed of the motor should fall before the circuit was opened.

RAWORTH R6 CONTROLLER

99. The diagram in Fig. 42 shows the combination of the motors, resistances, etc., on the various notches of a Raworth R6

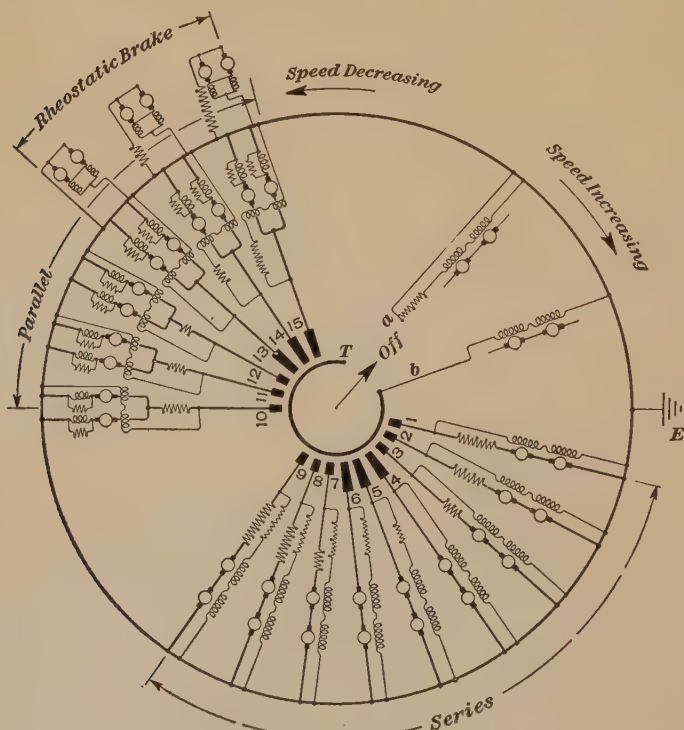


FIG. 42

controller arranged for series-parallel control of two shunt-wound motors. The outer circular ring of the diagram represents the

earth wire of the car, and the arrow in the centre of the illustration represents the controller handle, which is turned to the respective notches in order to complete a circuit from the trolley tapping *T* through the contacts and motors to earth at *E*.

In the off-position *a* the shunt-field windings of the two motors are in series with each other and with a shunt-field resistance, connected at this point as a discharge resistance. Before power is switched on to the motor armatures on the first notch, the shunt fields of the motors are fully excited on the transition notch *b* indicated in the diagram. The shunt windings of the two motors are permanently connected in series with each other.

100. Connections of Series Notches.—On notches 1, 2, and 3 the motor armatures are in series and series resistance is in circuit, the amount of resistance decreasing on successive notches. On notch 4 all the series resistance is cut out, and the shunt fields are fully excited; this notch gives a speed of from $3\frac{1}{2}$ to 6 miles per hour, according to the speed of the motor and the gear ratio adopted. On notches 5 and 6, resistance is inserted into the shunt-field circuit to weaken the field and to further increase the speed. A special point in the arrangement of this controller is that when the controller handle is moving in a clockwise direction, notches 7, 8, and 9 are the same as notch 6. Series resistance is needed on these notches on returning from parallel to the series connection; the method of bringing this about will be explained later.

101. Parallel Notches.—The motor armatures are switched out of series when no series resistance is in circuit, and are switched into parallel on notch 10, with the shunt-field resistance cut out of circuit, and with series resistance and the series-field coil and diverter combinations switched into circuit. The succeeding parallel notches cause the series resistance to be cut out step by step, and the shunt-field resistance to be again inserted, for running at high speeds.

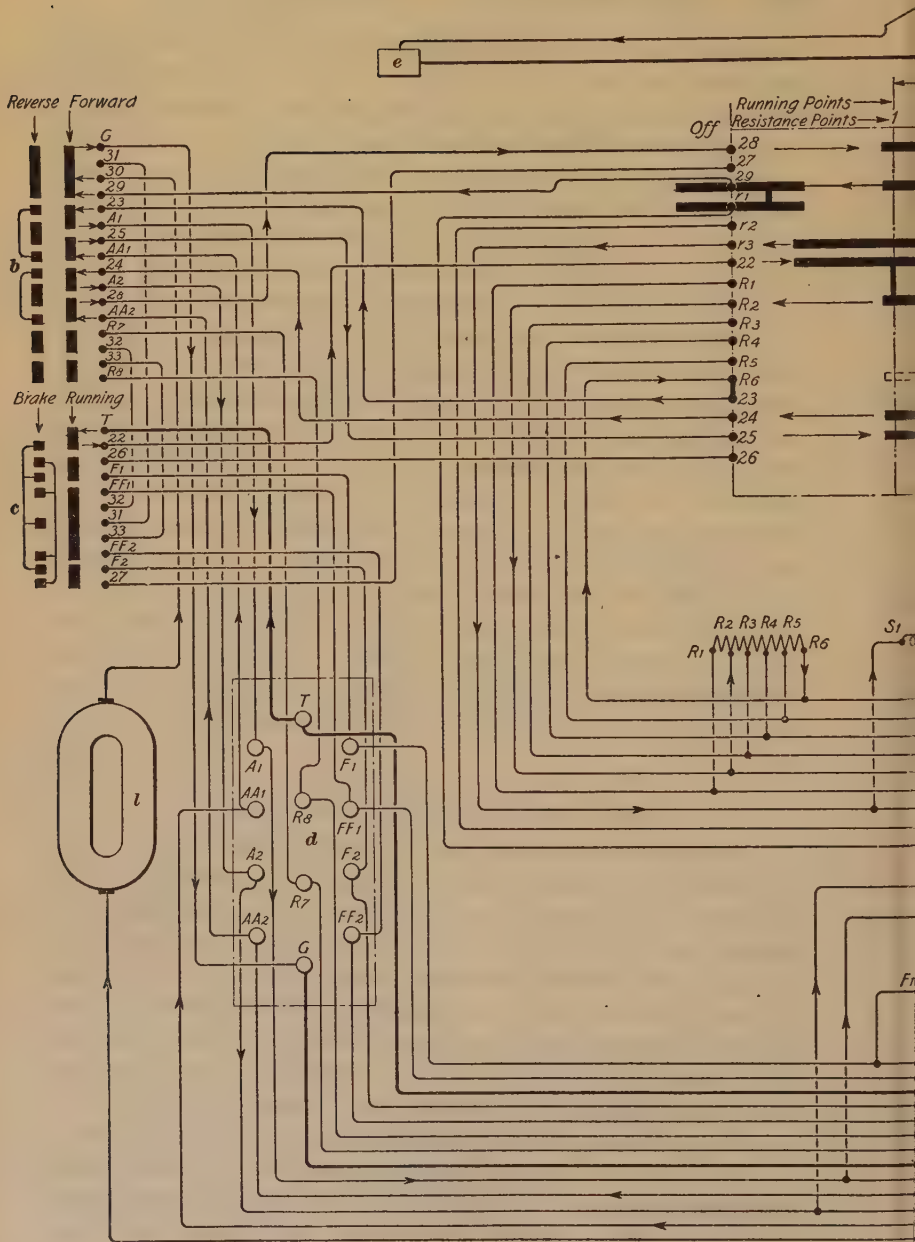
102. Rheostatic and Regenerative Braking.—The rheostatic-brake connections, notches 13, 14, and 15, in Fig. 42, provide for short-circuiting the motors as series-wound machines by the starting resistance, in the ordinary manner. By means of the

special arrangement of the contact segments on the main controller drum, the running notches *13* to *15* become rheostatic-braking notches when the controller handle is moved to them from the off-position. Apart from this special arrangement of notches *13* to *15*, every notch on the controller corresponds to a definite speed of the car. On any given notch, since the flux of each motor is constant, the speed of the car will remain nearly the same under practically all conditions. If the car runs from the level on to a rising incline, the current taken by the motors increases to supply the extra power required. If the car runs down-hill, the motors return current to the line and the car is prevented from largely exceeding its normal speed by the braking effect obtained. The steeper the gradient the greater is the current that will be returned to the line and also the greater will be the braking effect on the car. If the driver desires to reduce the speed of the car, the controller handle is simply moved to a lower notch, and the current returned to the line and also the braking effect are increased without locking the car wheels. To ensure that there is no resistance in the armature circuit when the motors are switched out of parallel and into series, the connections on notches *11* and *10*, when the controller handle is rotated in a counter-clockwise direction, are the same as on notch *12*.

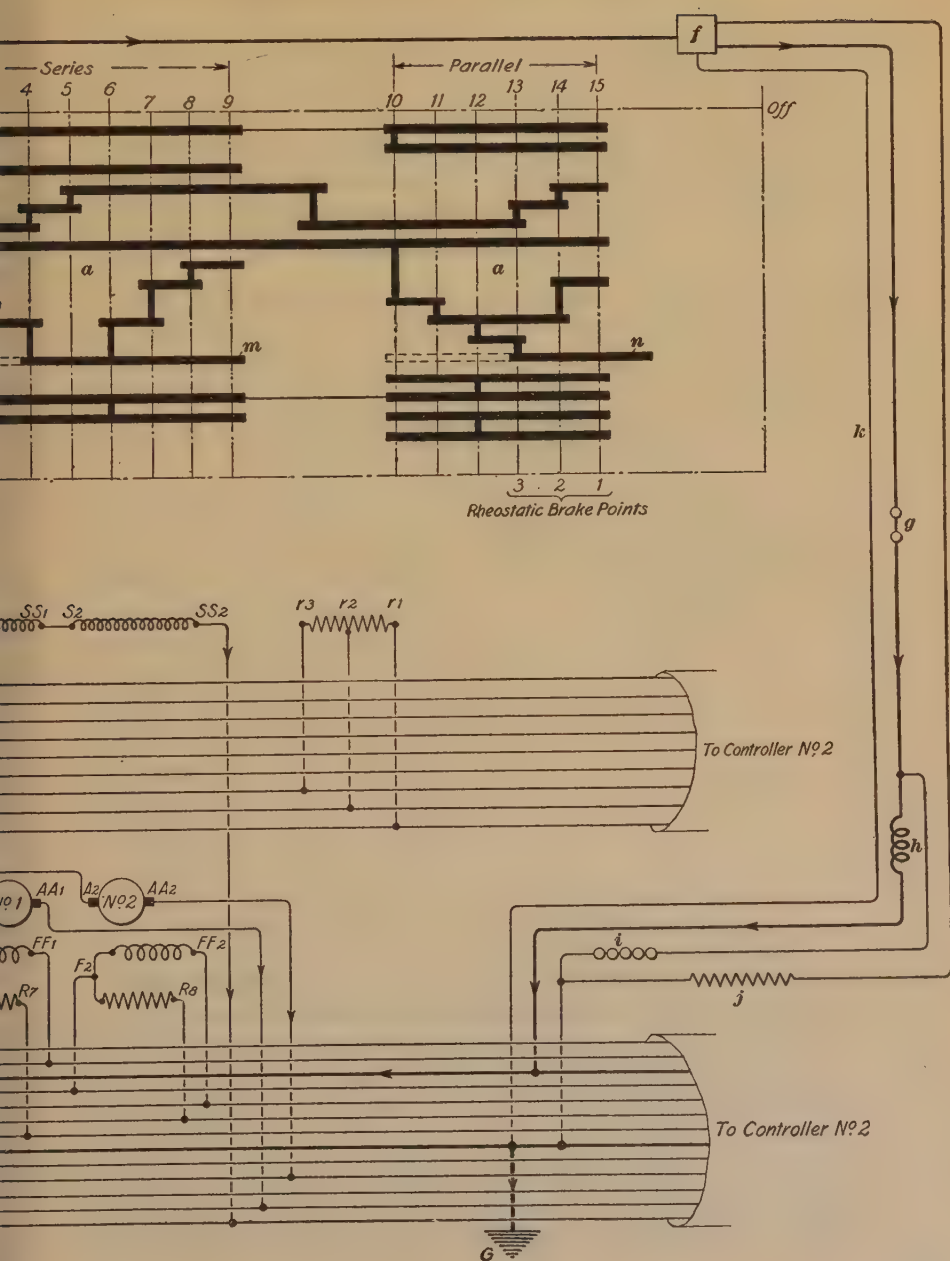
CAR WIRING FOR R6 CONTROLLERS

103. Power-Wiring Diagram.—A diagram of connections of the R6 regenerative controller is given in Fig. 43. In addition to the main power drum *a*, which carries contacts for 15 controller positions, there are a reverse drum *b*, with forward and reverse positions, and a brake drum *c*, which is normally closed in the running position, but may be placed in the brake position for rheostatic braking. Leads from the various motor windings and resistances are brought into the controller to a connection board *d*. The current from the trolley wire normally flows in the direction of the arrows, through an automatic overload circuit-breaker *e*, automatic potential switch *f*, the main fuse *g*, and kicking coil *h* to the trolley terminal *T* on the connection board and finger *T* on the brake cylinder *c*. The lightning

WIRING DIAGRAM OF R6 REGENER



CONTROLLER WITH TWO MOTORS



arrester *i* provides a path to earth for a lightning discharge. The trip coil or potential winding of the switch *f* is connected between the trolley tapping and earth by the wire *k*. A circuit to earth through a resistance *j* is closed by the automatic potential switch *f* if the power supply fails or the trolley wheel leaves the wire. The regenerated current is then passed through the resistance *j*, thus braking the car.

104. Connections on First Series Notch.—The path of the current through the controller and motors when the controller is on the first series notch and the reversing and brake drums are in the forward and running positions, respectively, is indicated by the arrows in Fig. 43, and is as follows: Trolley finger

T-brake drum—finger 22—22—main drum—

finger R2—resistance R2 to R6—finger R6—finger 23—23—reversing drum—finger A1—terminal A1—A1—armature of motor 1—AA1—terminal AA1—finger AA1—25—25—main drum—finger 24—24—reversing drum—finger A2—terminal A2—A2—armature of motor 2—AA2—terminal AA2—finger AA2—reversing drum—finger 28—28—main drum—finger 29—29—

finger r3—S1—shunt field of motor 1—SS1—S2—shunt field of motor 2—SS2—blow-out coil l—finger 30—

reversing drum—finger G—terminal G—and earth at G.

105. Special Arrangement of Contact Segments.—The positions of the contact segments of the power drum indicated in Fig. 43 are those which occur when the controller handle is moved round in a clockwise direction, which is equivalent to moving the contact segments to the left. With the segments as shown, the motor armatures are switched out of series connection when no series resistance is in circuit, and resistance is put in series with the two motors when they are connected in parallel. Segments *m* and *n*, however, are carried on a loose sleeve on the

controller shaft and are driven by a pin working in a slot, so that when the controller handle is turned in a counter-clockwise direction, equivalent to moving the controller contacts to the right, the loose segments hang back while the controller handle is moved over three notches, and on succeeding notches occupy the positions shown by the dotted lines. The effect of this special arrangement is to short-circuit the series resistance on notches 12, 11, 10, 3, 2, and 1, so that the armature circuit can be opened when the motors are switched out of parallel, and when the controller is returned to the off-position from notch 1, with no resistance in the armature circuit.

106. Connections for Rheostatic Braking.—When the controller handle is moved in a counter-clockwise direction to the rheostatic brake notch 1, the reversing drum being in the forward position and the brake drum on the brake notch, the path of the current is as follows: Earth at *G*—terminal *G*—finger *G*—reversing drum—finger 31—brake drum—

finger *F1*—terminal *F1*—*F1*—
series field of motor 1—*FF1*—
terminal *FF1*—finger *FF1*—

finger *F2*—terminal *F2*—*F2*—
series field of motor 2—*FF2*—
terminal *FF2*—finger *FF2*—

brake drum—

finger 26—26—main drum—finger
25—25—reversing drum—finger
AA1—terminal *AA1*—*AA1*
armature of motor 1—*A1*—
terminal *A1*—finger *A1*—
reversing drum—finger 23—23—

finger 27—27—main drum—finger
28—28—reversing drum—finger
AA2—terminal *AA2*—*AA2*
armature of motor 2—*A2*—ter-
minal *A2*—finger *A2*—reversing
drum—finger 24—24—

main drum—finger *R6*—series resistance *R6* to *R2*—finger *R2*—main drum—finger 22—brake drum—finger 31—31—reversing drum—finger *G*—terminal *G*—earth at *G*.

On the second brake notch 2 finger *R4* makes contact with a segment of the main drum and short-circuits all the resistance excepting that between *R6* and *R4*. On the third braking notch 3 all the resistance is short-circuited.

DIRECT-CURRENT RAILWAYS

(PART 1)

PRINCIPLES OF DESIGN

TYPES OF RAILWAYS

INTRODUCTION

1. **Differences Between Tramways and Railways.** — Electric railways might be said to be enlarged tramways, for the apparatus was first developed from that used on tramways, but modern lines show many differences. A fundamental one is that tramways run along main roads, while railways usually have their own private right of way. Other differences, in addition to cost, are : the railway rolling stock runs at a higher speed, has definite stopping places, and is arranged in trains, with suitable system of control. The railway staff is also similar to that required by the Board of Trade for steam railways, and there must be an adequate signalling system. Further, in order to obtain the authorization to construct a railway, a different Parliamentary procedure is necessary.

In addition to the passenger service, many electric locomotives are in use for shunting purposes and for hauling wagons round collieries, iron and steel works, factories, etc., and for connecting a works or mine with a main-line railway. All the early railways were worked with 500-volt direct current, the same as tramways, but the excessive current required at that voltage has led to the adoption of higher pressure, and in some cases 1,200 volts is used.

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2. Development of Electric Railways.—With the exception of the Liverpool Overhead and the Mersey Tunnel Railways, the early history of electric-railway enterprise in Great Britain has coincided with the development of underground railways in London. The congestion of surface traffic in the streets of that city and the impossibility of obtaining private rights of way in the densely-populated parts caused the railways to be placed in deep-level tunnels, or tubes. These tubes are reached by means of lifts, worked in most cases by electricity.

The first of these underground railways, the City & South London, opened in November, 1890, runs through two tubes $9\frac{1}{2}$ feet in diameter. The locomotive weighs $13\frac{1}{2}$ tons, and each coach, when loaded, weighs 30 tons. The average train speed is 15 miles per hour. Cast-iron hinged shoes fastened to the locomotive take direct current at 500 volts from a steel contact rail supported on insulators between the track rails. The track rails form the return mains, being bonded with copper. The feeders for the northern extensions to this line are supplied with current at 2,000 volts by a combination of the three-wire and five-wire systems. Motor generators reduce the pressure to 500 volts on the third rail, and a large storage battery is also used to equalize the load at the power house.

3. Central London Railway.—The Central London Railway is so constructed and the stations so placed that the trains run into them against a grade of 1 in 60, the departing trains being favoured by a grade of 1 in 30. This arrangement greatly economizes the energy required to operate the trains. When this railway was first opened, electric locomotives with gearless motors were used, but they caused such vibrations in the buildings directly over the tube that they had to be abandoned, and the trains now consist of motor coaches and trailer cars. Three substations supply current to the line, and rotary converters in these stations change the 5,000-volt three-phase alternating current from the power house into direct current at a pressure of 550 volts.

4. Electric Locomotives.—At first the motors of electric locomotives were mounted concentrically with the axle; but as the

TABLE I
DIRECT-CURRENT ELECTRIC RAILWAYS IN GREAT BRITAIN

Name of Railway	System Rail	Length Miles	Sharpest Curve Feet Radius	Maximum Grade	Average Distance Between Stations Yards	Voltage	Average Speed Miles Per Hour	Weight of Track Rail Pounds Per Yard
City & South London	3rd	7.2	350	1 in 50	700	500	15	80
Liverpool Overhead	3rd	6.5	430	1 in 40	670	500	19	56
Waterloo & City, London	3rd	1.5	330	1 in 30	2,640	500	18	86
Central London	3rd	6.3	330	1 in 30	800	550	15½	100
Mersey Tunnel	3rd and 4th	4.6	530	1 in 27	1,300	600	19	86
Great Northern & City, London	3rd and 4th	3.4	395	1 in 52	1,200	600	15	86
Liverpool to Southport Section, Lancashire & Yorkshire	3rd and 4th	33.0		1 in 85	2,200	600	30	86
Tyneside Lines of North Eastern	3rd	38.0	660	1 in 27	2,200	600	22	90
Metropolitan, London	3rd and 4th	30.0	360	1 in 40	2,200	600	22	86
Metropolitan District, London	3rd and 4th	24.3	330	1 in 40	1,160	600	17	86
Baker Street & Waterloo, London	3rd and 4th	4.2	330	1 in 30	880	600	14	90
Great Western & West London	3rd and 4th	4.7	400	1 in 60	1,000	600	16	97
Great Northern & Piccadilly, London	3rd and 4th	9.2	400	1 in 50	700	600	14	90
Charing Cross & Hampstead, London	3rd and 4th	7.7	400	1 in 60	880	600	14	90

power demand increased, it became impossible to find sufficient space for the motors, and the geared type had to be used. Locomotives are now produced in which the motors drive through connecting-rods and the track wheels are coupled together. This arrangement allows the motor to be placed well above the axle, thus raising the centre of gravity and lessening the wear and tear on the track.

In 1894, a self-contained electric locomotive was produced by Heilmann. This consisted of a 600-horsepower quick-speed steam engine driving a dynamo the output of which was 1,000 amperes at 400 volts. The current was supplied to motors mounted on the axles, and when tested the locomotive drew trains weighing 200 tons at a speed of 62 miles an hour. The type went out of use until recently, when the North British Railway have experimented with a locomotive using a steam turbine, instead of a quick-speed engine, as the prime mover.

5. Regeneration.—When the three-phase system was first applied to the working of Swiss mountain railways, it was found that a descending train could return energy to the line and thus be kept absolutely in check. This idea has since been developed under the name of **recuperation**, or **regeneration**, and some engineers think it will be a factor favourable to the electrification of railways on a large scale. It has already been successfully applied to several tramways working with direct current in Great Britain, as well as to three-phase railways.

Constructional and other details of the best-known direct-current electric railways in Great Britain are given in Table I.

CALCULATIONS

CYCLE OF OPERATIONS

6. Character of Service.—On urban and suburban lines there exists regular and constant working throughout the day, and the motors and other electrical apparatus must perform a definite cycle of operations with little variation; the trains are also

frequently started and stopped. On interurban railways, that is, railways running across country to connect several towns, the service is not so frequent and the trains run much faster than urban trains. They also start and stop much less frequently, and the motor equipments are often made to work with two systems and voltages, namely, direct current at 550 volts and single-phase alternating current at 1,000, or more, volts. For main-line railways the rolling stock is much heavier than for any of the foregoing, and the motors, controllers, and other apparatus must be very powerful. Quick acceleration is not important, but the motors must be capable of running for long periods on a fairly steady load without overheating.

In the case of *industrial railways*, regularity of working is conspicuously absent. The loading on the motors varies with the amount of goods to be hauled, and as a rule no time schedule must be kept. Locomotives are sometimes used for shunting wagons and coaches at terminal stations; their motor equipments must, of course, be capable of handling very irregular loads.

7. Operations of Urban and Suburban Railways.—The actual cycle of operations performed by an electric train in the regular class of urban and suburban service consists of: acceleration from rest; free or steady running with the current on; coasting, or running with current off; braking, or regenerating and braking; and standing in station.

Acceleration is the period during which the train starts from rest and reaches a more or less uniform speed. In this period, the output of the motors is chiefly utilized in imparting to the train the required velocity and in overcoming resistance to motion. The **free-running** or steady-running period includes the time during which approximately constant speed is maintained. In many cases, where stations are very close together, this period is omitted, there being no interval between the accelerating period and the coasting of the train. During the **coasting period** power is cut off from the propelling motors and the train is allowed to run by its own momentum. **Braking** is sometimes effected electrically by recuperation or return of

energy to the line, instead of mechanically by pressing brake blocks on to the wheels.

8. Averaging the Cycle.—Although the various parts of the cycle of operations of an electric railway are always present, with the possible exception of the free running, the duration of each part may vary within certain limits every time the cycle is performed. But it is generally sufficiently accurate to disregard these variations and to assume that the same cycle is performed each time, the duration of each part being taken as the average lengths of those parts in all the cycles. For example, suppose that a train must run from one terminus to the other in 26 minutes, stopping for 20 seconds at twelve intermediate stations.

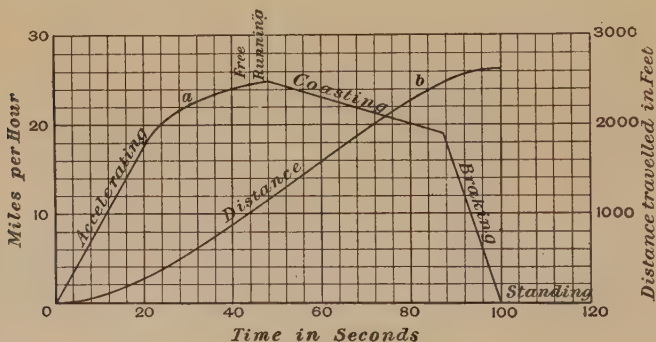


FIG. 1

If the distances between consecutive stations vary from 600 to 1,300 yards, and the total distance between the termini is $6\frac{1}{2}$ miles, the average distance between stations is 880 yards. As there are thirteen cycles, the average cycle consists of covering 880 yards in 2 minutes from start to start.

9. Speed-Time and Time-Distance Curves.—The cycle of operations on an electric railway may be shown by the curves in Fig. 1. Time, in seconds, is plotted as abscissæ, and the speed, in miles per hour, and the distance travelled, in feet, are plotted as ordinates. Curve *a* represents speed, and shows how it varies throughout the time of one cycle; curve *b* represents distance from the start, and indicates the position of the train at any

moment. Thus, 40 seconds from the start the train has travelled 900 feet, for the ordinate from 40 seconds crosses curve *b* at the point 900, the reading for distance being on the right-hand scale. The actual velocity at that instant is found by following the ordinate from 40 seconds until it crosses curve *a* and reading off the value on the left-hand scale; this will be found to be 24 miles per hour. The same set of curves may be used to show the five periods composing the cycle of operations. Thus it is seen that the accelerating period lasts 40 seconds, the free-running period lasts 8 seconds, the coasting period lasts 39 seconds, the braking period lasts 13 seconds, and finally the standing period lasts 20 seconds.

TRACTION RESISTANCE

10. Journal, Track, and Air Friction.—Unless supplied with power, a train moving on a level track will gradually lose its speed owing to **tractive resistance**, or the resistance to motion. This resistance is due to the friction of the axles in the bearings, or **journal friction**, to the resistance to the wheels rolling on the rails, or **track friction**, and to the resistance to the movement of the train through the atmosphere, or **air friction**.

Let A = journal friction, in pounds per ton;
 B = constant for track friction;
 C = constant for air friction;
 D = tractive resistance, in pounds per ton;
 V = speed of train, in miles per hour.

Then,
$$D = A + BV + CV^2$$

For the best modern main-line rolling stock, A may be taken as 4, but its value must sometimes be taken as great as 15. For such stock as colliery tubs it often reaches 40, and for contractors' tubs on light temporary tracks it reaches an even higher figure. For best conditions, B is given a value of .12; and $C = \frac{.00035 Q (7 + n)}{W}$, in which n represents the number of coaches in the train, Q is the area of the front of the train, in square feet, and W , the weight of the train, in tons.

EXAMPLE.—What is the tractive resistance of a 10-coach train that weighs 240 tons and has a front area of 85 square feet travelling at a speed of: (a) 10 miles per hour? (b) 30 miles per hour?

SOLUTION.—(a) To apply the formula just given, $A = 4$, $B = .12$,

$$C = \frac{.00035 \times 85 \times (7 + 10)}{240} = \frac{.00035 \times 85 \times 17}{240} = .0021. \quad \text{Then, if } V$$

$= 10$ mi. an hr., the tractive resistance

$$D = 4 + (.12 \times 10) + (.0021 \times 10^2) = 5.41 \text{ lb. per ton.} \quad \text{Ans.}$$

(b) If $V = 30$, the tractive resistance

$$D = 4 + (.12 \times 30) + (.0021 \times 30^2) = 9.49 \text{ lb. per ton.} \quad \text{Ans.}$$

11. Tractive Resistance of Wagons.—The tractive resistance of the wagons or trucks will vary between wide limits. The lowest values will be found with trucks equipped with roller bearings, such as are used on the North Eastern Railway, which at moderate speeds have a tractive resistance of 5 or 6 pounds per ton. With ordinary goods wagons, a probable value is 8 to 10 pounds per ton. For coal trucks and small wagons the resistance will be from 12 to 18 pounds per ton. Much naturally depends on the construction and nature of the bearings and the lubrication, which in small trucks is usually very poor. In a recent case, it was found that the tractive resistance of a train of colliery tubs, each weighing 13 hundredweights when loaded, was as high as 45 pounds per ton.

12. Train Friction.—The curves in Fig. 2 show the train friction of trains consisting of from one to five 45-ton coaches that have an effectual cross-sectional area of 110 square feet. They show that a single coach running at 75 miles per hour has a resistance of $62\frac{1}{2}$ pounds per ton, whereas a two-coach train has a resistance of only $41\frac{1}{4}$ pounds per ton. The journal friction of 5 pounds per ton is the same for all speeds, and is represented by a vertical dotted line. The track friction varies with the unevenness of the track and increases with the speed; it is shown by the slanting dotted line. The distance between the vertical and slanting dotted lines at any speed represents the track friction for that speed. The distance between the track-friction line and the vertical line passing through O represents the journal and track frictions combined. The distance between the dotted slanting line and the curved full lines represents the

air resistance for trains made up of different numbers of cars. With a single-coach train, travelling at a speed of 35 miles per

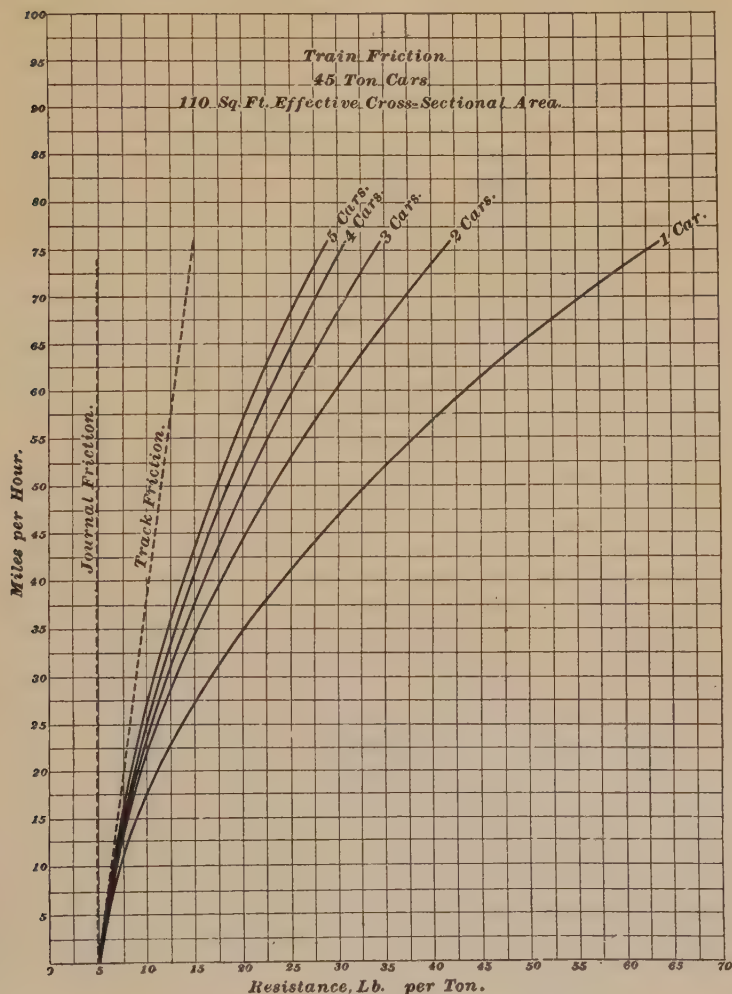


FIG. 2

hour, the air friction is about 11 pounds per ton. The resistance increases rapidly with increasing speeds, but its effects are not as pronounced with heavy trains as with light, because the end

area is practically the same, and the proportion of the total power used in overcoming air friction is therefore less. These curves show that, as regards power consumption, it is more economical to run coaches in trains than singly, especially for high speeds.

13. Influence of Track Curves.—Curves greatly increase the tractive resistance of the train, but the actual amount of this increase cannot be easily obtained, for it depends on the sharpness of the curve and the condition of the roadbed. As a rough approximation, it may be assumed that on a level curve in good order with a 500-foot radius, a train of from 6 to 10 six-wheeled coaches will be opposed by an extra resistance to traction of about 12 pounds for every ton weight of the train. For a radius of 1,000 feet, the extra resistance will be 6 pounds; for a radius of 1,500 feet, 4 pounds; and for 2,000 feet, about 3 pounds. For main-line traffic, railway engineers try to keep the minimum radius of curvature at $\frac{1}{2}$ mile, when the extra resistance is about $2\frac{1}{3}$ pounds per ton weight of train.

ACCELERATION

14. Comparison of Steam and Electric Traction.—One of the strongest arguments in favour of electricity as a motive power

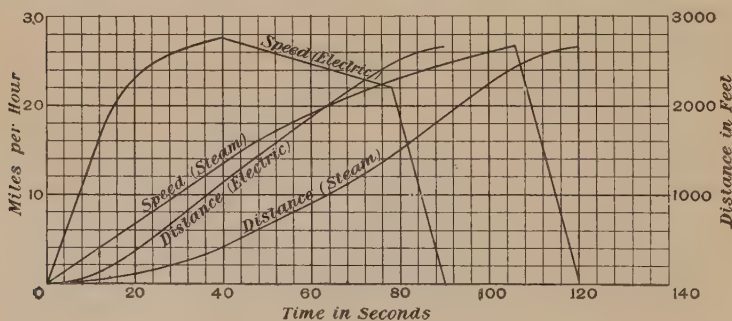


FIG. 3

for railways is that it gives rapid **acceleration**, or the ability to speed up quickly. This enables electric trains on urban and suburban railways to run at a higher average speed than is

possible with steam locomotives, and this is an important advantage where the stations are only $\frac{1}{2}$ or 1 mile apart, as is the case with many of the electric railways of Great Britain. In Fig. 3 are given the speed-time and time-distance curves of steam and electric trains that start from rest and run $\frac{1}{2}$ mile. The electric train has an initial acceleration of 2 feet per second per second; the steam train has an initial acceleration of $\frac{1}{2}$ foot per second per second. This enables the electric train to reach its greatest speed in 40 seconds, coast for 38 seconds, reaching the station in 90 seconds from the start, whereas the steam train only reaches its maximum speed in 106 seconds, when it must immediately brake, and it reaches the station in 120 seconds from the start.

15. Advantages of Quick Acceleration.—The advantages of quick acceleration are an increased train mileage per day or per annum, which gives an increased power of earning money for the same number of trains, the same staff, the same track, and an increase of about 28 per cent. in the average speed. The increase in average speed, giving a consequent saving in time, is a considerable attraction to possible passengers in view of competition with other means of conveyance, such as tramways and motor buses. On long-distance railways, where stops are infrequent, and on industrial railways quick acceleration is not so important.

16. Force Required to Accelerate.—As speed is usually measured in miles per hour or in feet per second, acceleration is expressed in terms of miles per hour per second or feet per second per second. For example, if a train starts from rest and acquires a speed of 30 miles per hour in 25 seconds, the acceleration is 1·2 miles per hour per second, or 1·76 feet per second per second.

Let P = force, in pounds per ton ;

W = weight of train or other body, in pounds ;

f = acceleration desired, in feet per second per second ;

g = acceleration due to gravity.

Then, the force required to produce any desired acceleration is

$$P = \frac{Wf}{g} \quad (1)$$

This formula shows that the acceleration is strictly proportional to the force producing it. Thus, if the value of P is one-half the value of W , the rate of acceleration is 16.1 feet per second per second, or one-half that due to gravity. For a weight of 1 ton and an acceleration of 1 foot per second per second, the value of P is 69.5, or roughly 70, pounds per ton. The foregoing formula may therefore be written

$$P = 70 f \quad (2)$$

But if the rate of acceleration f' is desired in miles per hour per second, the formula becomes

$$P = 102 f' \quad (3)$$

The force given by these formulæ must in all cases be added to the force necessary to overcome the tractive resistance, which is easily found by multiplying the assumed or calculated number of pounds per ton by the total weight of the train, in tons.

17. Rotational Acceleration.—When a train must be accelerated from rest, it is necessary to set in motion not only the train, but also the wheels and axles and the armatures of the driving motors in a rotational sense, and after the train is in motion it possesses momentum by reason of its linear velocity and by reason of the rotation of all its revolving parts. Both of these components of the total stored energy, therefore, must be supplied by means of the accelerating force. The force required for **rotational acceleration** is proportional to that required for ordinary or **translational acceleration**, since the two accelerations are proportional; this additional force is generally taken as one-tenth of that required for translational acceleration.

18. Force to Overcome Gravity.—When it is required to accelerate a train up a gradient, an additional force must be applied equal to the gravity component due to the gradient.

The gradient may be expressed as $\frac{\text{rise of incline, in feet}}{\text{length of incline, in feet}}$.

Let W_t = weight of train, in tons ;

G = gradient expressed as a fraction ;

F_w = force required to overcome weight of car acting down the gradient, in pounds.

Then, $F_w = 2,240 W_t G$

EXAMPLE.—What force is required to overcome the force of gravity acting on a train weighing 100 tons on a gradient that rises 10 feet in every 500 feet?

SOLUTION.—Applying the formula just given,

$$F_w = 2,240 \times 100 \times \frac{1}{50} = 4,480 \text{ lb. Ans.}$$

19. Producing a Given Acceleration.—The total force required to produce a given acceleration in a body is the sum of the forces required to overcome the tractive resistance and the gradient, if any, and the forces necessary to accelerate the motion of a moving body and to produce rotational acceleration.

EXAMPLE.—How much force is required to give a 180-ton train a velocity of 30 miles per hour in 22 seconds? The track has a gradient of 1 in 50, and there is a tractive resistance of 10 pounds to the ton.

SOLUTION.—To attain a velocity of 30 mi. per hr. in 22 sec., the train must have a rate of acceleration of $\frac{30}{22} = 1.36$ mi. per hr. per sec. By formula 3, Art. 16, the force required to accelerate the motion of a body weighing 1 ton at a rate of 1.36 mi. per hr. per sec. is $102 \times 1.36 = 138.72$ lb. Therefore, to accelerate the movement of a 180-ton train, the force is $180 \times 138.72 = 24,970$ lb., nearly. From Art. 17, the rotational acceleration is one-tenth of this, or 2,497 lb. As the tractive resistance is 10 lb. per ton, for the entire train the total tractive resistance is $180 \times 10 = 1,800$ lb. From Art. 18, the force required to overcome a gradient of 1 in 50 is $2,240 \times 180 \times \frac{1}{50} = 8,064$ lb. Therefore, the total force required to give the train the desired velocity is

$$24,970 + 2,497 + 1,800 + 8,064 = 37,331 \text{ lb. Ans.}$$

20. Finding Acceleration From Total Force.—If the total force applied to a train is known, the accelerating force may be found by applying the following rules:

Rule.—I. *From the total force, deduct the forces necessary to overcome tractive resistance and the gradients, if any; the remainder is the combined accelerating force.*

II. *Divide the combined accelerating force by 1.1 to find the total translational accelerating force; dividing this by the weight of the train, in tons, gives the translational accelerating force, in pounds per ton.*

III. *Divide the translational accelerating force per ton by 70 to find the acceleration in feet per second per second, or divide by 102 to find the acceleration in miles per hour per second.*

EXAMPLE.—What acceleration will be produced if a total force of 37,331 pounds is applied to a 180-ton train, when the track has a gradient of 1 in 50 and there is a tractive resistance of 10 pounds per ton ?

SOLUTION.—For a 180-ton train, the force necessary to overcome a tractive resistance of 10 lb. per ton is $10 \times 180 = 1,800$ lb. To overcome a gradient of 1 in 50 requires a force of $2,240 \times 180 \times \frac{1}{50} = 8,064$ lb. Deducting the sum of these forces, 9,864 lb., from 37,331 lb. leaves 27,467 lb. as the combined accelerating force. The force required to accelerate the train is therefore $27,467 \div 1.1 = 24,970$ lb., nearly, or $24,970 \div 180 = 138.72$ lb. per ton. By formula 3, Art. 16, $P = 102 f'$, and, transposing,

$$f' = \frac{P}{102} = \frac{138.72}{102} = 1.36 \text{ mi. per hr. per sec. Ans.}$$

21. Limits to Acceleration.—The maximum acceleration in the speed of a train is limited by the maximum tractive force that can be applied. The maximum tractive force depends on the adhesion between the driving wheels and the rails, and therefore on the weight on the driving wheels and the roughness of the contact surfaces of wheels and rails. The maximum tractive force or adhesive force that can be obtained by the driving wheels may be found by multiplying the total weight on these wheels by a factor, called the

TABLE II
COEFFICIENT OF ADHESION

Condition of Rails	Values of Coefficient
Dry	$\frac{1}{4}$ to $\frac{1}{5}$
Clean wet	$\frac{1}{5}$ to $\frac{1}{6}$
Dirty wet	$\frac{1}{5}$ to $\frac{1}{7}$
Greasy	$\frac{1}{7}$ to $\frac{1}{9}$
Wet, strewn with sand	$\frac{1}{8}$ to $\frac{1}{6}$

coefficient of adhesion, which depends on the condition of the rails. The usual values for the coefficient of adhesion are given in Table II. If the rails are perfectly dry, a coefficient of $\frac{1}{4}$ may be used, and if the rails are wet and sanded slightly, a coefficient of $\frac{1}{5}$ or $\frac{1}{6}$ is obtainable. If the turning force applied to the wheels is greater than the adhesive force between the wheels and rails, the wheels will slip.

22. Adhesion Under Braking Conditions.—The effectiveness of braking depends on the friction between the wheels and the brakes and between the wheels and the rails. The retardation

produced by braking differs from acceleration in that the brakes are generally applied to most of the wheels of a train, whereas usually only a few wheels are used as driving wheels. With the usual coefficients of adhesion, if all wheels are braked, the corresponding maximum values of retardation are as given in Table III.

TABLE III
MAXIMUM VALUES OF
RETARDATION

Coefficient of Adhesion	Feet Per Second Per Second
$\frac{1}{4}$	8.0
$\frac{1}{5}$	6.4
$\frac{1}{6}$	5.3
$\frac{1}{7}$	4.6
$\frac{1}{8}$	3.6

23. Acceleration of Steam Locomotives and Electric-Motor Coaches.

On trains hauled by steam locomotives, the acceleration is usually very much lower than that which is commonly employed on electric trains. The acceleration of a steam train seldom exceeds 1.8 feet per second per second; on the Liverpool Overhead Electric Railway, an acceleration as much as 4.2 feet per second per second has been recorded.

EXAMPLE 1.—What is the maximum acceleration that can be applied to a train weighing 180 tons that is composed of a 50-ton steam locomotive and several coaches? The weight on the driving wheels of the locomotive is 36 tons; the coefficient of adhesion, $\frac{1}{8}$; the tractive resistance, 10 pounds per ton; and the gradient, 1 in 50.

SOLUTION.—The maximum tractive force that can be applied to the train is $\frac{1}{8} \times 36 \times 2,240 = 13,440$ lb. As the force required to overcome tractive resistance is $10 \times 180 = 1,800$ lb., and the force required to overcome the gradient is $2,240 \times 180 \times \frac{1}{50} = 8,064$ lb., the combined accelerating force is $13,440 - (8,064 + 1,800) = 3,576$ lb. The translational accelerating force is $3,576 \div 1.1 = 3,251$ lb., or $\frac{3,251}{180} = 18$ lb. per ton, nearly. This force, by formula 2, Art. 16, gives an acceleration of $\frac{18}{70} = .257$ ft. per sec. per sec. Ans.

EXAMPLE 2.—What is the maximum acceleration that can be applied to a train weighing 180 tons, it being composed of four electric coaches that weigh 36 tons each and two coaches that weigh 18 tons each? Each electric coach is equipped with four motors, one on each axle, and the other conditions remain as in example 1.

SOLUTION.—Since the entire weight of each electric coach is carried by driving wheels, the total weight available for adhesion is $4 \times 36 = 144$

tons. With a coefficient of adhesion of $\frac{1}{6}$, the maximum tractive force that can be applied to the train is $\frac{1}{6} \times 144 \times 2,240 = 53,760$ lb. Deducting from this the forces required to overcome the tractive resistance and the gradient ($1,800 + 8,064$) gives for the combined force of acceleration $53,760 - 9,864 = 43,896$ lb. The translational accelerating force is $43,896 \div 1.1 = 39,905$ lb., or $\frac{39,905}{180} = 222$ lb. per ton, nearly. This

force, by formula 2, Art. 16, gives an acceleration of $\frac{222}{70} = 3.17$ ft. per sec. per sec., which is nearly 12 times the acceleration of the steam locomotive.

CONTROL

MULTIPLE-UNIT SYSTEM

24. Necessity of Central Control.—A train consisting of a number of electric-motor coaches will accelerate faster than a train drawn by a locomotive, because of the multiplicity of driving axles and therefore of motors. But all these motors must be capable of being controlled from any motor coach, and the control must be suited to any number of coaches. Such trains are therefore equipped on the **multiple-unit system**, each train being made up of a number of units each complete in itself, but connected together electrically by means of control circuits. The control circuits are arranged so that electromagnetic switches on each coach may be operated simultaneously from one point, thus giving control of all the motors.

25. Advantages of Multiple-Unit Control.—Since it makes no difference to the speed or accelerating power of a train whether coaches are added or taken off, by the multiple-unit system trains may be made up to suit the requirements of the traffic without interfering with the ability of any train to maintain a high average speed. As the acceleration and average speeds are high, the same track and rolling stock can be made to produce more train miles each day. It is also possible to control the trains from either end, thus minimizing the shunting necessary at terminal stations when locomotives are used.

CHOICE OF MOTORS

26. Points Governing Choice.—When choosing the motors for any particular work, care must be taken that they have sufficient mechanical strength and will not overheat or spark; they should also be able to accelerate rapidly when going up steep gradients. The motors should be of standard sizes and must fit the space available between the track wheels. They should have maximum speeds on straight level track that will enable the train to keep schedule time, yet this speed should not be much in excess of that normally required. Their number,

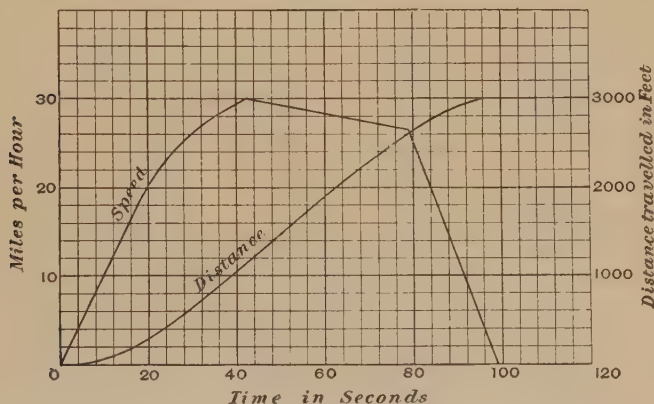


FIG. 4.

size, and arrangement depend on the acceleration required and the weight of the trains.

27. Determination of an Average Cycle.—When a train is running between stations the speed varies at different points because of different conditions of track and grade, and also because of the acceleration at starting and the retardation at stopping. At some part of the run the speed usually reaches a more or less constant value. The actual values of the speed, as well as the relative lengths of time of accelerating, running at full speed, coasting, and braking will vary with each case. The cycle of operations for a special case is shown in Fig. 4. Starting from zero, the speed curve rises uniformly to 19.8 miles per

hour in 19·3 seconds; it then rises less rapidly until 30 miles per hour is reached at the end of 42 seconds. At this point the power is shut off and coasting begins, and the speed drops to 26·3 miles per hour at the end of 79 seconds, at which point the brakes are applied and the train is brought to rest in 99 seconds from the start. During this time the distance travelled has been 3,000 feet, or ·568 of a mile, as shown by the distance curve.

28. Probable Weight of Train.—To find the size of motors that will perform a certain cycle of operations in a certain time, it is first of all necessary to estimate the weight of the train. Corridor coaches for main-line railways weigh about 25 tons each and the dining cars about 35 tons, while the coaches used on urban electric railways to carry 48 passengers weigh about 20 tons without, and 30 tons with, motor equipment. Trailers, or coaches not equipped with motors, weigh about 16 tons each. The weight of the passengers is generally allowed for at the rate of 16 to the ton.

EXAMPLE.—Find the weight of an electric train that consists of two motor coaches and four trailers. The weight of each motor coach is 30 tons and the weight of each trailer is 16 tons.

SOLUTION.—Allowing 16 passengers to the ton, the weight of the passengers in each coach may be taken as $\frac{48}{16} = 3$ tons, and for the train $6 \times 3 = 18$ tons. The weight of the motor coaches is $2 \times 30 = 60$ tons; of the trailer $4 \times 16 = 64$ tons. The weight of the entire train is therefore $18 + 60 + 64 = 142$ tons. Ans.

29. Maximum Horsepower of Motors.—Throughout the acceleration period of the cycle of operations, the pull exerted is at its maximum value, and the horsepower reaches its highest value at the end of this period.

Let $P' =$ tractive force of motors, in pounds;
 $V =$ speed, in miles per hour.

Then, the maximum horsepower of the motors will be

$$\text{H.P.} = \frac{5,280 P' V}{33,000 \times 60}$$

EXAMPLE.—What is (a) the maximum pull and (b) the horsepower of the motors, if a train weighing 142 tons reaches a speed of 19·8 miles

per hour in 19·3 seconds? Assume that the tractive resistance is 10 pounds per ton.

SOLUTION.—(a) The pull required to accelerate at the rate of $\frac{19.8}{19.3} = 1.025$ mi. per hr. per sec. is, from formula 3, Art. 16, $P = 102 \times 1.025 = 104.55$ lb. For 142 tons, the force is $142 \times 104.55 = 14,846$ lb. The rotational acceleration is one-tenth of this, or $\frac{14,846}{10} = 1,485$ lb., nearly. The tractive resistance is $10 \times 142 = 1,420$ lb. Therefore, the maximum pull required for acceleration is

$$14,846 + 1,485 + 1,420 = 17,751 \text{ lb. Ans.}$$

(b) Then, by the formula just given, the horsepower exerted by the motors will be

$$\frac{5,280 \times 17,751 \times 19.8}{33,000 \times 60} = 937 \text{ H.P., nearly. Ans.}$$

ENERGY CONSUMPTION

30. **Performance Curves.**—When a motor has been chosen, its energy consumption may be determined by means of performance curves. The base line of the curves, shown in Fig. 5, gives the current required, in amperes; the left-hand margin

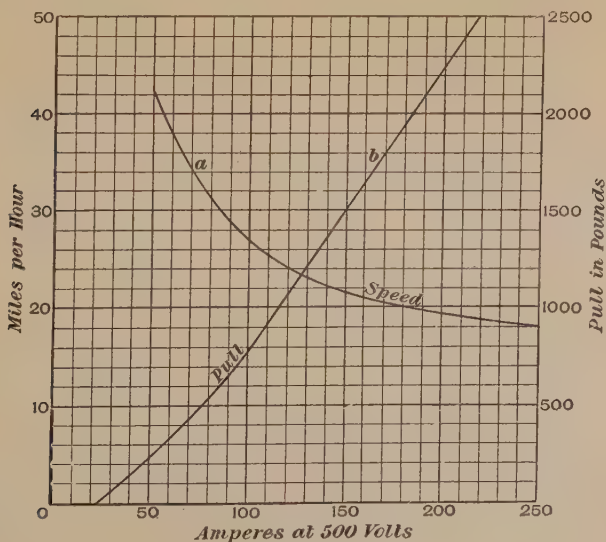


FIG. 5

gives the speed, in miles per hour ; and the right-hand margin gives the pull, in pounds. Curve *a* shows the relation between speed and current ; for example, when the current is 150 amperes, at 500 volts pressure, the speed is 21·5 miles per hour. Curve *b* shows the relation between the tractive effort, or pull, in pounds, and the current taken by the motors. When the current is 150 amperes the pull is shown to be 1,500 pounds.

31. Variation of Current During Acceleration.—The variations of current during switching on are of the same character as those which occur with tramcar controllers. If a car or train is started from rest and allowed to accelerate at the maximum rate as shown by the speed curve, Fig. 6, the current required will vary greatly. For the case shown, the motors are connected two in series during the first 9 seconds, and the resistance is cut out step by step ; the subsequent 10·3 seconds represents the second stage of the switching, when the motors are connected in parallel with each other, a resistance being in series with them, and the resistance is again cut out step by step. Owing to these variations of current, the maximum current is much greater than the average. Therefore, when a calculation is made for the horsepower exerted by a train during a given cycle, the figure arrived at is the average value. For instance, the 937 horsepower found in the example in Art. 29 is the average value, and the maximum may be as high as 1,100 horsepower. These momentary values of the current or of horsepower are of no great importance in the consideration of the energy consumption, but they are of great importance when the limit of adhesion is considered, and when the supply of current to the train is taken into account, because they affect the size of the generating plant, the feeder, and the distribution systems.

32. Period of Switching.—The current curve, Fig. 6, shows that for the first 9 seconds, with the motors in series, the current is steady at 740 amperes. Then it jumps to 1,480 amperes, with the motors in parallel, where it remains for 10·3 seconds ; for the next 23·2 seconds it drops, quite rapidly at first, until it reaches a value of 685 amperes, at which point the current is cut off. The speed curve shows that the motors accelerated

at a uniform rate until the current taken began to fall from 1,480 amperes, at which time the train had a speed of 19.8 miles per hour. The train then accelerated more slowly until it reached the speed of 30 miles per hour at the end of 42.5 seconds, when

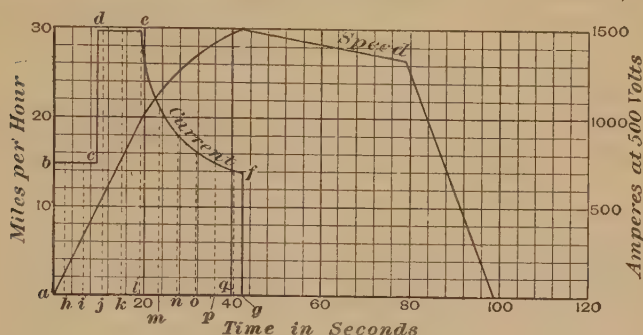


FIG. 6

the current was cut off. The train then coasted along by its own momentum for 37 seconds, when the brakes were applied. This, however, is a modified curve, for the means used to control or

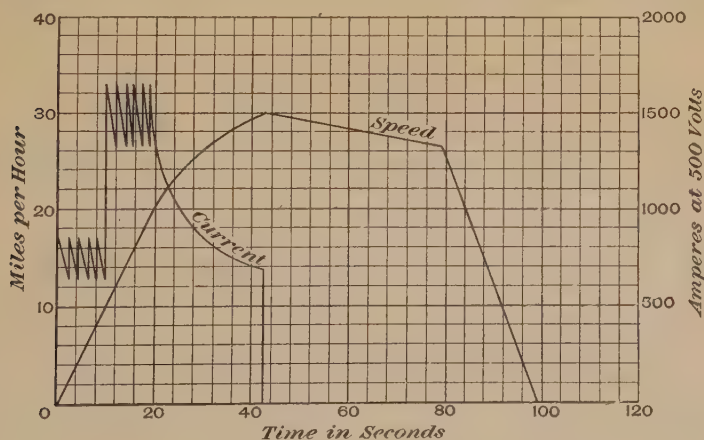


FIG. 7

regulate the motors cannot maintain the current at the constant values shown during the first 19.3 seconds. During this time, which is known as the **period of switching**, the current varies somewhat, as shown in Fig. 7. When any section of resistance

is cut out, the current rises quickly and then gradually drops as the speed increases.

33. Watt-Hours Per Ton-Mile.—The calculation of the energy consumption may be arrived at by finding the area included between the base line and the current curve *a b c d e f g* in Fig. 6. This can be done by dividing the area into 10 equal parts and measuring the height of each as shown by the lines *h, i, j, k, l, m, n, o, p, q*. Adding these heights together and dividing by 10 gives the average height of the area *a b c d e f g*, and reading this off on the right-hand scale gives 1,000 amperes. The distance from *a* to *g*, as read on the bottom scale, is 42.5 seconds, so that the area *a b c d e f g* represents 42,500 ampere-seconds.

Assume that the curve, Fig. 7, gives the results for a train weighing 142 tons, which during each cycle covers a distance of 3,000 feet, or .568 mile. The usual voltage of supply is 500, therefore the total electric energy supplied to the train during each cycle is $500 \times 42,500$ watt-seconds, or $\frac{500 \times 42,500}{60 \times 60}$ = 5,903 watt-hours, nearly. Therefore, the energy consumption expressed in watt-hours per ton-mile is $\frac{5,903}{142 \times .568} = 73$, nearly.

34. Cost of Energy for a Given Train Service.—In steam-railway practice, it is customary to reckon in train-miles, and the energy or fuel consumption, etc., are given at so much per train-mile. As there is usually one locomotive to each train, it is practically the same as saying per locomotive mile. In electric-railway practice, the trains are usually made up of motor coaches and trailers, and the numbers of these to a train can be varied quite easily to suit traffic conditions throughout the day and at various seasons of the year. It is therefore much more correct and convenient to express the energy, or fuel consumption, at so much per ton-mile. Knowing, or assuming, the amount of energy required in watt-hours per ton-mile, as well as the cost per kilowatt-hour at the power house, it is possible to estimate quite closely the cost of energy that may be required for the operation of any particular railway.

EXAMPLE.—What is the daily cost of energy for running trains on a railway that has a daily train-mileage of 3,600, if one half the trains weigh 150 tons and the other half 80 tons? The energy consumption is 65 watt-hours per ton-mile, and the cost of energy is .5d. per kilowatt-hour.

SOLUTION.—The ton-mileage of the railway is $\left(150 \times \frac{3,600}{2}\right) + \left(80 \times \frac{3,600}{2}\right)$
 $= 414,000$. The consumption of energy is, therefore, $414,000 \times 65$
 $= 26,910,000$ watt-hr., or nearly 27,000 K.W.-hr. At .5d. per K.W.-hr.,
 the daily cost for energy is

$$\frac{.5 \times 27,000}{240} = \text{£}56, \text{ nearly. Ans.}$$

35. Factors Varying the Amount of Energy.—The consumption of energy depends on many factors. For example, a careless application of the current to the motors may greatly increase the consumption; some trains take 50 per cent. more than others from this cause. Gradients, too, increase the consumption, especially if there is any starting of the train when mounting the grade. Signal checks or stops due to irregular working of the traffic are other causes of additional energy consumption. The consumption of energy on one underground railway in London is increased 15 per cent. by this cause, while on an interurban railway it does not exceed 8 per cent. Some tube railways, as the Central London Railway, are constructed with each station at the top of a gradient; this plan results in a saving of energy that is not obtained when the track is level. There are also the losses in feeders, which may amount to 5 per cent.; if there is a long transmission line, the losses on that may be another 10 per cent.

36. Relation of Acceleration and Kinetic Energy.—If a train accelerates rapidly, it is possible to switch off the power some time before the brakes are applied and a part of the kinetic energy is used in overcoming the tractive resistance. In this way it is possible to reduce the total energy expended by making the stored energy do useful work. The speed curves *a* and *b*, Fig. 8, show that power is supplied in the first case for 40 seconds only, and in the second case the power supply is continued for 72 seconds. In both cases the trains, each weighing 150 tons, are to start, travel $\frac{1}{2}$ mile, and stop, in 90 seconds. Curve *a*

shows the speed of one train, which at the start has an acceleration of 2 feet per second per second, and reaches its maximum speed of 27·5 miles per hour in 40 seconds, then coasts for 40 seconds, or until the speed has dropped to 22·1 miles per hour, before the brakes are applied. Curve *b* shows the speed of the other train, which at first accelerated at the rate of 1·2 feet per second per second, and reached its maximum speed of 31·2 miles per hour in 72 seconds, just at the time the brakes

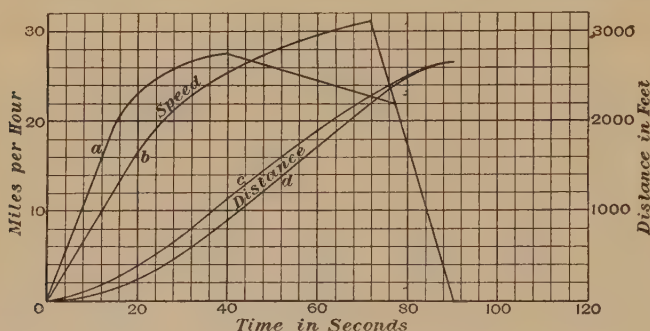


FIG. 8

had to be applied. Curves *c* and *d* are the respective distance curves.

Let W = weight of train, in pounds ;

V = speed of train, in feet per second ;

g = acceleration due to gravity, taken as 32·2.

Then, for a train,

$$\text{the kinetic energy in foot-pounds} = \frac{W V^2}{2g}$$

As 22·1 miles per hour is $\frac{22 \cdot 1 \times 5,280}{60 \times 60} = 32 \cdot 4$ feet per second,

very nearly, the train having the speed shown by curve *a*, at the instant the brakes are applied, has a kinetic energy of $\frac{150 \times 2,240 \times 32 \cdot 4^2}{2 \times 32 \cdot 2} = 5,477,000$ foot-pounds, approximately.

A speed of 31·2 miles per hour is $\frac{31 \cdot 2 \times 5,280}{60 \times 60} = 45 \cdot 8$ feet per second ; therefore, the train having the speed shown by curve *b*

has, at the instant the brakes are applied, a kinetic energy of

$$\frac{150 \times 2,240 \times 45 \cdot 8^2}{2 \times 32 \cdot 2} = 10,944,200 \text{ foot-pounds, approximately.}$$

37. Use of Brakes in Stopping.—The kinetic energy due to the speed of a train at the time the brakes are applied must be dissipated mostly as heat which is developed by the friction between the wheels and the brake blocks. The greater the amount of kinetic energy, the greater the wear on both brake blocks and wheels, and also the greater the total amount of energy supplied. Considered from the standpoint of economy of power, it would be advisable to allow a train to come to a standstill without applying the brakes. This plan of stopping trains is not adopted because of the loss in time due to low retardation. By the use of brakes for stopping, the number of train-miles in a given time can be increased, and therefore the earning capacity of the train may be increased.

In the preceding article it is shown that the kinetic energy of a train moving at a speed of 31·2 miles per hour is nearly double the kinetic energy of a train moving at a speed of 22·1 miles per hour. The wear on the brake blocks is much greater in the first case than in the second.

38. Effect of High Acceleration on Motors and Plant.—High acceleration of trains gives economy in energy consumption, provided the kinetic energy is partly used in overcoming tractive resistance before the brakes are applied for stopping the train, but larger motors are required than for low acceleration. The large motors place more weight on the driving wheels; they also make a greater maximum demand on the generating station, and this necessitates a larger and more expensive generating plant and more expensive feeder and distribution systems. The most favourable acceleration for any one case can only be determined by carefully working out the calculations on different assumptions, and considering the advantages and disadvantages of each result.

39. Examples of Energy Consumption.—When the Liverpool Overhead Railway was first equipped the acceleration of the trains

was 1·6 feet per second per second, whereas now it is 4·2 feet per second per second with a consumption of 137 watt-hours per ton-mile.

On the Central London Railway the energy consumption is very low, being about 44 watt-hours per ton-mile, which result is obtained chiefly by means of the special arrangement of gradients. At starting, a down gradient assists the motors; and on approaching a station, the train is retarded by an up gradient and brakes combined. In this way, the energy absorbed in the brakes is reduced. The stations are about $\frac{1}{2}$ mile apart, and the mean speed, including stops, is about $15\frac{1}{2}$ miles per hour. For the Inner Circle line of the London Metropolitan Railway the manufacturers' guarantees were between 65 and 75 watt-hours per ton-mile. The average distance between stations is $\frac{1}{2}$ mile, and the mean speed, including stops, about 16 miles per hour.

40. To Find Horsepower of a Locomotive.—There is usually no precise information as to the duty required from an industrial locomotive. In most cases it is required to haul a number of wagons or tubs, and assumptions must be made as to their number and weight. The ordinary 10-ton coal truck weighs 5 or 6 tons. Goods wagons are much heavier, while coal tubs straight from the collieries are lighter. In some cases the latter weigh only 13 hundredweights when fully loaded. An acceleration of approximately ·5 foot per second per second is generally considered sufficient. Having obtained all data available and made assumptions from them, a figure for the pull at a given speed on the level is arrived at; a pull of 5 tons at a speed of 10 miles per hour may be allowed for an industrial locomotive.

EXAMPLE.—What size motor equipment is required for a locomotive which is to exert a pull on the level of 11,200 pounds at a speed of 10 miles per hour? The tractive resistance is 10 pounds per ton and the adhesion coefficient is $\frac{1}{7}$.

SOLUTION.—If W is the weight of the locomotive, in tons, the force required to keep the locomotive running at 10 mi. per hr., allowing a tractive resistance of 10 lb. per ton, is $10 W$ lb. Adding to this the pull which the locomotive must exert, namely, 11,200 lb., the total pull given by the motors must be $11,200 + 10 W$ lb. Allowing for an adhesion coefficient of $\frac{1}{7}$, the weight of the locomotive is $W = 7 \times \frac{(11,200 + 10 W)}{2,240}$

tons. $W = \frac{78,400 + 70 W}{2,240}$, or $2,240 W = 78,400 + 70 W$; $2,170 W = 78,400$, and $W = \frac{78,400}{2,170} = 36.1$ tons, nearly. The total pull, therefore, that must be exerted by the motors will be $11,200 + 36.2 \times 10 = 11,562$ lb. This pull at a speed of 10 mi. per hr. is equivalent to an output of

$$\frac{11,562 \times 10 \times 5,280}{33,000 \times 60} = 308 \text{ H.P., nearly. Ans.}$$

41. Limit of Weight on Axle.—A maximum weight of 18 tons on each axle may be assumed for a first-class main-line railway on which the track and the bridges are very strongly built. The latest steam locomotives of the Great Western and Midland Railways have a maximum weight on axles of about $19\frac{1}{2}$ tons. On electric locomotives, and particularly on motor coaches, it is so easy to distribute the load over several motors that the maximum weight on the axle need never exceed 12 tons. This means cheaper tracks, bridges, etc. In addition, as the motion of electric motors is purely rotary, the wear and tear on the rails and wheels is less and the adhesion between them is greater for a given weight on the axles than with steam locomotives. The reciprocating engines of the latter with various unbalanced parts give a hammer blow which is very destructive to the rails. When dividing up the maximum power required to haul a given train, it should be noted that the number of motors must be even, so that they may be connected in series and in parallel. Four or eight motors is the most usual practice.

42. Necessity for Adequate Sanding.—For ordinary passenger traffic carried in motor coaches and trailers, the necessity for using sand only occurs occasionally, as when starting on greasy rails. With electric locomotives there are usually fewer driving axles and so more sand may be required, especially when hauling heavy loads up gradients. When providing sanding arrangements, the climatic conditions of the country where the locomotive is going to work must be considered. For example, in a moist climate like that of Great Britain the necessity for sanding is greater than in drier and warmer countries.

ENERGY SUPPLY

METHODS OF COLLECTING CURRENT

43. Overhead Conductors and Conductor Rails.—There are two methods of conveying current to electric trains : by means of copper overhead conductors, and by means of steel-rail conductors laid along the track. They are usually called the **overhead-wire system** and the **third-rail system**. The overhead wire is usually employed for interurban railways and light-weight locomotives, and the third rail is employed for urban and suburban railways. The overhead system is practically identical with that used for tramways, being modified where necessary for a high-speed service of trains. In the case of industrial railways, it is simplified by the use of wooden poles, etc. On tramway systems, the highest voltage permitted by the Board of Trade is 550 volts ; but as there is usually no such restriction on railways, it is possible to use 1,000 volts or higher. This, of course, necessitates better insulation.

44. Third and Fourth Rails.—The third rail is usually of steel of higher conductivity than the track rails, and it is supported on insulators. Contact shoes attached to the locomotive or the motor coaches slide along the rail as the train moves forwards, and the current which is picked up passes through flexible cables to the wiring of the car, thence through the fuses, controllers, resistances, etc., to the motors. In some cases, the return current passes back to the generating station or substation by means of the track rails ; in other cases, it returns through a second conductor rail, which is usually called the **fourth rail**. Where both third and fourth rails are used, as in the case of the Metropolitan, the Metropolitan District, and the Mersey Tunnel lines, the positive, or third, rail is outside and about 18 inches from the track rail, while the negative rail is laid along the sleepers midway between the track rails.

45. Calculations for Overhead Wires.—Many of the calculations for overhead wires are similar to those for tramways,

but the current is usually heavier and there is a less frequent service. For example, in almost all tramway systems a number of cars are at work simultaneously; whereas, in railways where an overhead wire is used, it frequently happens that not more than one or two trains are taking current at the same time. In tramway work, it is usual to design the overhead line and feeder system so that the drop of volts between the power station and the cars, under the worst conditions, will not exceed a certain amount, often 15 per cent. In a small railway, operating at most two trains, there are great fluctuations in the load, so that it is wise to limit this voltage drop to a smaller value, for instance, 10 per cent.

46. Voltage Drop in Wires and Rails.—Take the case of a locomotive which must run over a line 2 miles in length, hauling a load in both directions. In one direction it works against a gradient of 1 in 20, and in the other it works with the gradient. The power station is at the end of the line, that is, at the top of the gradient. The locomotive requires for starting a current of 160 amperes, and for running up the gradient a current of 120 amperes. The overhead line consists of two trolley wires, each No. 0000 S.W.G. hard copper having a resistance of $\cdot 337$ ohm per mile. As the two trolley wires are in parallel their combined resistance will be $\frac{\cdot 337}{2}$ ohm per mile. Then the volts drop on the line will be $160 \times 2 \times \frac{\cdot 337}{2} = 54$ volts, nearly, at starting at the bottom of the gradient, which is about 10 per cent., and $120 \times 2 \times \frac{\cdot 337}{2} = 40\cdot 4$, or 40 volts, nearly, when running up the gradient.

A fair allowance for the drop in the track rails is 10 volts with 160 amperes, and 7·5 volts with 120 amperes, so that the total drops will be 64 and 47·5 volts. The generating station supplies current to the overhead line at 550 volts, and therefore the voltage at the locomotive every time it starts will be $550 - 64 = 486$ volts, and when it begins to climb the gradient $550 - 47\cdot 5 = 502\cdot 5$ volts.

47. Advantage of High Voltage.—Suppose that, in the example given in Art. 46, instead of using a 550-volt supply, the generating station gives 1,100 volts. The current required by the locomotive will be 80 amperes for starting and 60 amperes for climbing the gradient, as the power is the same as before. If the drop is the same percentage of the supply voltage as before, namely, about 10 per cent., then, with the same No. 0000 S.W.G. wires, the current can be transmitted 8 miles instead of 2 miles. This can be expressed in general terms as follows: *With a given per cent. loss, the distance over which any given power can be transmitted varies as the square of the voltage of transmission.*

Of course, the voltage is limited to that for which it is possible to build the motors. By the use of commutating poles and extra-quality insulation, it is now possible to build traction-motors of large size for 1,000 or 1,200 volts. If two such motors are connected permanently in series and treated as a single unit, the voltage of the overhead wire may be 2,000 or 2,400 volts.

48. Calculations for Third Rail.—Hard-steel track rails have a resistance about 11 to 13 times that of copper of similar cross-section. On the other hand, rails can be made of nearly pure iron at a reasonable price and have a resistance only about 7 times that of copper. The conductor rails of the London underground railways have a resistance 6·4 times that of copper of similar cross-section. These rails contain ·05 per cent. of carbon, ·019 per cent. of manganese, ·054 per cent. of phosphorus, ·059 per cent. of silicon, and ·03 per cent. of sulphur. Ordinary track-rail steel usually contains about ·4 per cent. of carbon and ·85 per cent. of manganese.

As a copper conductor 1 square inch in area has a resistance of ·042 ohm per mile, an iron conductor rail weighing 50 pounds per yard and measuring 5 square inches in cross-section will have a resistance of $\frac{·042}{5} \times 7 = ·0588$ ohm per mile. Similarly, a conductor rail weighing 100 pounds per yard has a resistance of ·0294 ohm per mile, and will carry a current of 1,000 amperes with a drop of $1,000 \times ·0294 = 29·4$ volts per mile.

49. Distance Between Substations.—On the Metropolitan District Railway of London, the distance from substation to substation along the line varies from one to several miles. On the busiest section, from Earl's Court to Mansion House, the distances between substations are 1, 1.4, 1.35, and 1.3 miles. On the route of the Central London Railway, which is $6\frac{1}{4}$ miles long, there are three substations. The voltage of supply is usually 600, and the drop is generally taken at about 10 per cent., or 60 volts, half of which is in the positive or third rail.

EXAMPLE.—A train requires 1,800 amperes when it is midway between two substations; the third rail weighs 100 pounds per yard and has a resistance of .0294 ohm per mile. Allowing for a drop of 30 volts on the third rail between each substation and the train, what should be the distance apart of the substations?

SOLUTION.—Each substation will deliver 900 amperes, and as the resistance of a 100-lb. conductor rail is .0294 ohm per mi., the drop per mi. is $900 \times .0294 = 26.46$ volts. Therefore, the distance apart of the substations must be $\frac{2 \times 30}{26.46} = 2\frac{1}{4}$ mi., nearly. Ans.

50. Need of a Fourth Rail.—Board of Trade regulations demand that when tramway rails form part of the electric circuit the potential difference between any two points of this uninsulated return must not exceed 7 volts. Although it is not always necessary for electric railways to comply with this regulation, it is generally done when electrolysis may injure property. When there are few, if any, water or gas pipes, as in the open country, there is no objection to the use of the track rails for carrying the return current, even if the drop is 20 or 30 volts, especially as wooden sleepers help to insulate the track rails from earth. On the other hand, for a heavy railway in a large city, such as London, it is not advisable to allow such a drop on the track rails. The question then arises, Is it better to use track rails and employ whatever means are necessary to reduce the drop to something less than 7 volts, or should an insulated return conductor rail be used? The answer depends on circumstances, more particularly on what means are necessary to reduce the drop to within the specified limit. On the Central

London Railway no special precautions need be taken, for the actual drop in the rails does not exceed 4 volts. On the Metropolitan District Railway of London, if the track rails were used without any auxiliary means for reducing voltage, the drop would be 30 volts. This railway has, however, a separate insulated fourth rail.

TRACK

SAFETY IN WORKING

51. Feeder Systems.—The proper arrangement of feeder systems for electric railways must be considered for each particular case from the following points of view: (a) Minimum disturbance of traffic in case of any failure of feeders, distribution conductors, etc.; (b) most convenient organization for controlling the feeder system; (c) precautions against danger to railway employees. In an extensive railway system in which there are several lines or branches, it would be a very serious drawback to electrification if all parts of the system were put out of operation when a fault occurred at one point. Of course, a complete breakdown of the power house might cause a stoppage of the entire system, but the chances of this are very remote, for modern power houses are equipped with several separate and complete generating units. Also, storage batteries are frequently installed in substations for direct-current railways. Besides, there is a tendency for electric-supply systems to help each other in cases of emergency. By dividing the feeder system into a sufficient number of sections, each of which can be isolated from the others, a short circuit or other failure on any one of them can be dealt with, so that other parts of the system are not affected. This dividing up of the feeder system into sections is called **sectionalizing**.

52. Control From Substations.—In an electric tramway the control is usually centred in the generating station, from which separate direct-current feeders are taken to the various parts of the tramway system. If the electric railway does not differ

greatly from a tramway, the same method is applicable ; but most electric railways do differ widely from tramways. A usual method is to distribute current from a number of substations which are supplied from a single power house, with high-tension alternating current. In this case the control must be divided, since the current supplied to the trains is not distributed from a single central point. Each substation, by means of its switch-gear, has control of a certain portion of the railway, while the supply to the substations is controlled at the power house. Of course, all the substations are in telephonic communication with the power house.

53. Protection of Employees.—Means must be taken to protect those working on the line. It is not sufficient to provide

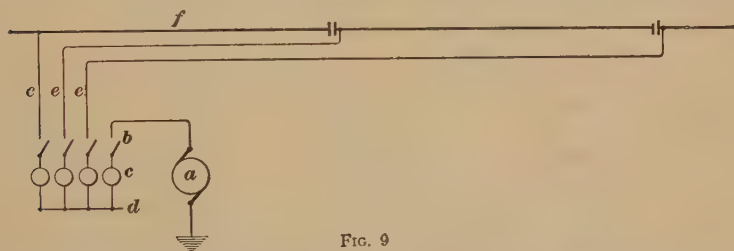


FIG. 9

for sectionalizing the line unless provision is also made so that two neighbouring sections cannot be connected together by a passing train. Suppose, for example, that a fault has occurred on a certain section, and that the section has been isolated by means of switches controlling the supply of current to it. If while men are working on this section a train closes the connection between this section and a neighbouring one which is alive, the result will be disastrous to the repairing gang. The simplest method of providing the necessary protection is to insert between any two sections a special length of conductor called a *train section*, which may be disconnected from the other sections.

54. Sectionalizing Feeder Systems.—In Fig. 9 is shown a simple arrangement for sectionalizing the feeders of a railway. The generator *a* is connected through an automatic circuit-breaker *b* and ammeter *c* to a bus-bar *d* ; from this bus-bar

three feeders *e* are taken to three sections of the overhead line *f*, each feeder being provided with an ammeter and automatic circuit-breaker. By opening any one circuit-breaker the corresponding section of overhead line can be disconnected from the generator.

This arrangement is sufficient for the case in which the electric train or electric locomotive obtains current from the overhead line by means of a single collector. However, the train or locomotive may be fitted, as in Fig. 10, with two overhead collectors *a*, which are separated sufficiently to bridge the section insulators *b*. Then, if the section of overhead line to the right of the section insulator *a* is under repair and the locomotive gets into the position shown, current will pass from the live

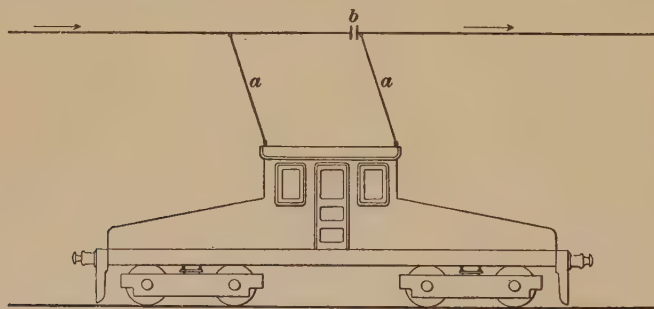


FIG. 10

section on the left through the collectors on the locomotive to the section under repair along the path indicated by the arrows.

55. Train Sections.—A train section is that part of the supply conductor between two insulators *a, a*, Fig. 11, which are so far apart that the collectors of a train or locomotive cannot bridge across the section between the insulators. One of these insulators is provided with a bridging switch *b*, which is normally kept closed, so that the train section forms part of one of the ordinary sections. When the supply is cut off from any section by means of the feeder switch in the generating station, the foreman in charge of the repairing gang must open the bridging switch, or *train-section switch*, and be responsible for keeping it open, until the work is completed. If an electric

train has a motor coach at each end and trailer cars between, then, if each motor coach has two collectors, the state of affairs shown in Fig. 12 is quite possible. As shown, the train section *a* is bridged by the four collectors, and current will flow in the direction indicated by the arrows. It is thus evident that complete protection can only be provided if the train section is

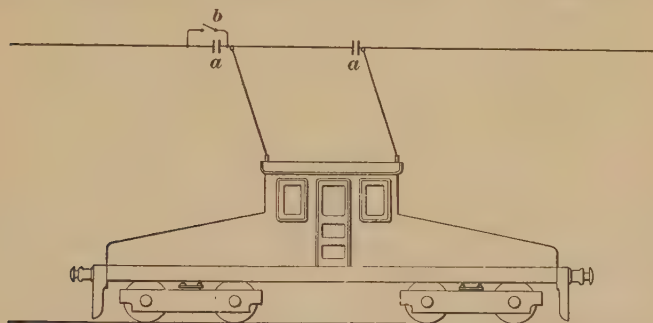


FIG. 11

longer than the greatest distance between the front and rear collectors on a single train.

56. Sectionalization of Third Rail.—Third-rail or third-and-fourth-rail systems supplied from a number of substations may be sectionalized in one of two ways: either each substation may have entire control over one section, or each section may be

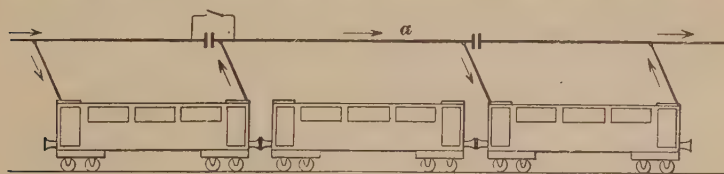


FIG. 12

under the control of two adjacent substations. The first method is shown in Fig. 13, where *a* is the rotary or generator, which is connected to the third rail *b* through the ammeter *c* and automatic switch *d*. The train sections *e* are connected to the conductor by the bridging switches *f*. In this system, the train sections are approximately midway between substations, and the substation attendants have no control over them; therefore,

when any work is to be done, the foreman of the repairing gang must open the bridging switches. The second method is shown in Fig. 14, where the generator, or rotary, *a* is connected to the third rail *b* through the automatic switch *d*, ammeter *c*, bus-bars *e*, and feeders *f*. The train sections *g* are connected direct

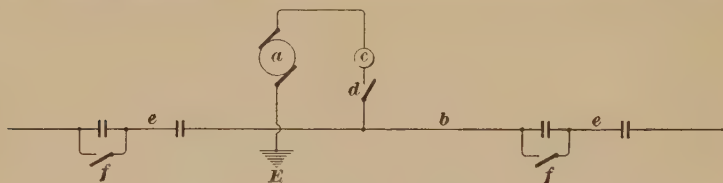


FIG. 13

to the substation bus-bars and are controlled by the substation attendants.

Apart from this difference, the main distinction between these two methods is an electric one. The second method has the

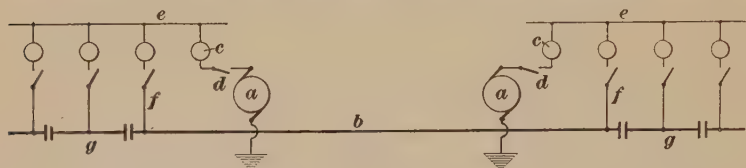


FIG. 14

advantage over the first in that current is supplied to each section simultaneously from both ends instead of from a single point at its centre. Assuming a train requires 2,000 amperes, then, by the arrangement shown in Fig. 15, the supply conductor has to



FIG. 15

carry the full current, while, with the arrangement shown in Fig. 16, each supply conductor or feeder carries only half the total current required by the train. Therefore, the conductors required in the latter case will have only half the cross-section required in the other,

The figures shown have been prepared for the third-rail system only, but the same principles apply to the third-and-fourth-rail system, except that both conductor rails must be sectionalized in the same way, and positive and negative feeders and circuit-breakers must be provided.

57. Junctions and Cross-Overs.—The question of sectionalization has been considered solely as if the line were continuous and without branches, junctions, and cross-overs. Apart from



FIG. 16

the considerations introduced by the location of the substations, the design of the feeder system must be examined in the light of the arrangement of the track. The introduction of section insulators or their equivalents has for its principal object the minimizing of the disturbance of traffic consequent on a breakdown on one part of the system, and where there are junctions or cross-overs, special sections must be provided; however, there can be no advantage in providing a degree of sectionalization that cannot be actually utilized in case of necessity.

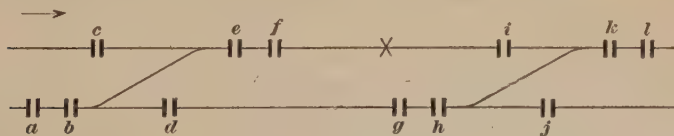


FIG. 17

58. Layout of Cross-Over.—A diagram showing the arrangement of the section insulators in the conductor rails at a double cross-over is given in Fig. 17. The insulators in the main rails are shown at *a*, *b*, *c*, *j*, *k*, *l*, and the insulators in the portion between the cross-over sections are shown at *d*, *e*, *f*, *g*, *h*, *i*. The insulators *b*, *e*, *h*, *k* must be placed at such a distance from the points of the cross-over roads that a train can run beyond the points and still have current to run back over the cross-over. Thus, supposing there is a derailment at the point *X* so that

the conductor rails are short-circuited, the section insulators at *e*, *f*, and *i* should be opened. Then, a train coming in the direction of the arrow will stop between the points of the cross-over road and the section insulator *e*, back up over the cross-over, and proceed on the other line to the next cross-over, where it will return to its own line. In this way single-line working is provided past the obstruction and the disturbance of traffic is minimized as far as possible. Junctions are treated in the same way; namely, the whole of a junction is isolated

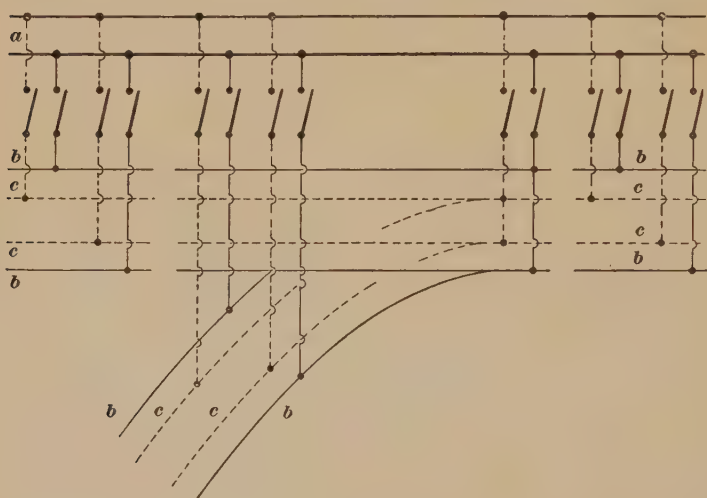


FIG. 18

from the adjacent parts. This isolation is shown in Fig. 18, by the openings in the third and fourth rails *b*, *c*. Switches connect or disconnect the bus-bars *a* from the conductor rails *b* and *c*.

ELECTRIFICATION OF RAILWAYS

COMPARATIVE COST OF STEAM AND ELECTRIC TRACTION

59. Reasons for Electrification.—In some cases, special circumstances, such as the smoke nuisance and ventilation of underground railways and tunnels, have practically forced railway

companies to adopt electric traction; for example, the London underground railways, the Mersey Tunnel Railway, and many long tunnels in the United States. But, as a rule, in the absence of such conditions, there must be some adequate financial inducement before any railway company will seriously consider the question of electrification, for the change from steam to electricity involves a considerable outlay of capital. The most obvious advantage that can be suggested for urban and suburban railways is the possibility of a large increase in the working capacity and the revenue-earning capacity, due to increased acceleration.

TABLE IV
RESULTS OF ELECTRIFICATION

Items	Mersey Tunnel Railway		North Eastern Railway	
	Steam	Electric	Steam	Electric
Passengers carried, exclusive of season-ticket holders . .	2,844,700	4,153,777	2,844,000	3,548,000
Gross receipts . . .	£29,470	£37,358	£129,000	£151,000
Working expenses . .	£28,082	£32,442	£42,761	£47,779
Train-mileage . . .	155,039	401,046		

60. Results of Electrification.—In Table IV are given the results of electrifying the Mersey Tunnel Railway and the Tyne-side lines of the North Eastern Railway. In the case of the Mersey Tunnel Railway, the figures are for 6 months only; in the other case they are given for a year, with the exception of the passengers carried, which are only for 6 months. The running cost, per train-mile, of the North Eastern Railway before electrification was 1s. 2½d. ; afterwards it was 6¾d.

61. Comparative Working Expenses.—In order to arrive at a clear understanding of the financial aspect of the electrification problem, it is necessary to study the comparison as to working expenses between steam and electric operation. The chief department of a railway which is affected by electrification is that

which deals with haulage, namely, the locomotive department; therefore, if any saving is to be shown, it must be in the expenses incurred in that department. In other respects the cost of working is not much altered, as, for example, traffic organization, permanent way, and signalling. With the third-rail system there is a little more for the permanent-way men to attend to, but, on the other hand, the station attendants, by being more regularly employed throughout the day, can handle much more luggage, and get the passengers on board and the trains away expeditiously. Further, the time taken in lighting up, banking fires, taking in fuel and water, etc., with steam locomotives, is saved with electric traction.

62. Cost of Fuel With Steam Locomotive.—The largest item of the working expenses of steam locomotives is the cost of fuel. The locomotive is by no means as economical a power producer as a generating station. An ordinary passenger locomotive usually requires about 3·5 pounds of coal to produce 1 indicated horsepower-hour, whereas a generating station requires anything from 2 pounds downwards. As the average cost per ton for locomotive coal in Great Britain, including delivery, is 16s., 3·5 pounds will cost ·3d. This corresponds, approximately, to ·35d. per brake horsepower-hour. If to this is added ·04d. for water, which includes all the costs incurred in water columns, pumping stations, etc., the total for fuel and water amounts to about ·39d. per brake horsepower-hour.

63. Cost of Electric Energy.—If electricity is used, the efficiency of transmission and the efficiency of the motors, etc., must be taken into account, and these vary a great deal. The efficiency of transmission may be anything from 80 per cent. with substations and conductor rails, to 90 per cent. without substations. The efficiency of motors, etc., may be taken as between 75 per cent. and 85 per cent., according as to whether there is much or little rheostatic loss. Taking as average figures 85 per cent. and 80 per cent., respectively, the combined efficiency is $\cdot 85 \times 80$ per cent. = 68 per cent. A railway company could not purchase electrical energy in Great Britain on a fairly large scale for much less than ·5d. per kilowatt-hour. This is on the

assumption that there is a separate source of supply available, from which the railway could purchase electricity in the same way as they purchase coal. With the combined efficiency of 68 per cent., 1 brake horsepower-hour will be equivalent to

$$\frac{746}{\cdot 68 \times 1,000} = 1\cdot 1 \text{ kilowatt-hours.}$$

The cost of 1 brake horsepower-hour on the train will therefore be $1\cdot 1 \times \cdot 5 = \cdot 55d$.

64. Comparison of Water-Power and Coal.—The figures just given show that there is little prospect of economy in the cost of fuel in a country where fuel is cheap. Under other conditions, however, a different result might be obtained. For example, suppose that by means of water-power, or otherwise, electricity could be supplied at $\cdot 35d$. per unit, and that coal costs from 25s. to 35s. per ton, as is the case in some countries which have plenty of water-power but little or no coal; then the fuel and water would cost more than the electrical energy, and there would be a well-marked economy in favour of electricity. Again, more economical means of generating electric power on a large scale by means of steam plant, and especially by gas producers, are being introduced. This is all in favour of electric railways, for these more economical methods can only be applied to the full extent for the generation of electric power on a large scale in a power house.

65. Expenses.—In addition to the fuel cost, there are, of course, many other expenses in railway working, and in these the electrical method shows marked advantages; for example, wages, oil, stores, repairs, and renewals. There can be no doubt that the item for wages can be largely reduced, and even halved, by electrification. A steam locomotive requires two men, whereas one driver is sufficient for an electric train, and he is driving all the time. On the other hand, a steam locomotive has to have the steam raised and fires banked. The oil and stores account is less; motors usually have self-contained self-oiling bearings, so that the driver does not need to go about with a large oil can before he starts on a trip. The cleaning, when in the shed, is also very much less. The repairs and renewals of steam locomotives are heavy items, due to the presence of the boiler and

the reciprocating mechanism, whereas the electrical equipment of an electric locomotive or a motor coach is comparatively simple and costs less to keep in repair.

66. Summary.—As the comparison of locomotive expenses with steam and electrical operation is not a simple matter, electrification is still regarded as an open question in many quarters. No attempt can be made here to summarize the financial advantages to be expected from electrification, as these vary greatly according to the conditions of each individual case. But as more data become available, it is probable that there will be no difficulty in demonstrating that electric traction has advantages and possibilities which are not possessed by the older form of locomotion. There are indications at the present time that main-line railways will have to spend large sums of money for strengthening bridges, lengthening platforms, etc., in order to cope with the increasing steam traffic. With electric traction this will not be necessary, as shorter, lighter trains running more quickly and more frequently will satisfactorily meet the increased traffic conditions.

DIRECT-CURRENT RAILWAYS

(PART 2)

ROLLING-STOCK ACCESSORIES

RAILWAY MOTORS

CONSTRUCTION AND RATING OF RAILWAY MOTORS

1. **Comparison of Railway and Tramway Motors.**—Direct-current railway motors are similar in type and general construction to tramway motors, and the early types were practically identical. As railways developed, however, the horsepower required for motor coaches and locomotives increased, in some cases to several thousand horsepower, and thus necessitated differences in size and construction of the motors. The increase in output of the motors is not accompanied by any large increase in space available, because the standard railway gauge of 4 feet 8½ inches is the same as that of most tramways, and the diameter of the driving wheels of electric locomotives and motor coaches is in many cases not much larger than the standard 33-inch diameter wheel of tramcars.

In order to utilize all available space for a railway motor, the bearing at the pinion end projects underneath the armature end connections, and, in some cases, partly under the core itself; the bearing at the commutator end also projects under the commutator hub.

2. **Rating of Railway Motors.**—As the load on railway motors is intermittent, the horsepower of such motors is given on the

basis of a run of 1 hour. That is, after the motor has been running at full rated load for 1 hour on a circuit giving the pressure for which the motor is designed, the rise in temperature of any part of the motor as measured by a thermometer must not exceed 135° F., or 75° C. The temperature of the surrounding atmosphere during the test should not be above 77° F., or 25° C. In case it is, proper correction should be made, so that a maximum temperature of 212° F., or 100° C., for any part of the motor shall not be exceeded. If the temperature of a motor exceeds the given value at the end of a run of 1 hour on a certain load, the load should be reduced to comply with the temperature rise and the motor given a lower horsepower rating.

GEARLESS MOTORS

3. Features of Gearless Motors.—A type of motor used on railways, but not on tramways, is the **gearless motor**, in which the armature is mounted concentrically with the driving axle, thus making it possible to dispense with bearings and pinion, so that the space usually taken up by them becomes available for the active electrical parts of the motor. Such a motor must necessarily run at the comparatively slow speed of the axle, and therefore the motor is much larger for a given output than would be the case if it were designed to run at high speed and were geared to the axle. The advantage of extra space available, owing to absence of bearings and gearing, is therefore to some extent counterbalanced by the increased size of the motor. It is necessary to provide the largest railway motors with forced ventilation in order that they may carry the required load without overheating.

4. Arrangement of Armature.—There are two methods of supporting the armatures of gearless motors. The first method is to fix the armature spider directly on the driving axle. It is a somewhat objectionable arrangement owing to the fact that it is usually impossible to support the magnet field system on springs, because the movement of the springs would cause the distance between the poles and the armature to change. If

the field systems are not spring-borne, the total dead weight on the axles and driving wheels is very great, and this weight will cause heavy blows on the track rails wherever there are inequalities, as at the joints, points, and crossings; such blows would be destructive both to the track and the motors.

The second method of supporting the armature is to fix it on a sleeve which loosely surrounds the driving axle, and which is connected to the axle or driving wheels by spring couplings.

5. Early Type of Axle-Mounted Motors.—One of the first railways to have gearless motors was the City & South London Railway, and Fig. 1 represents an early type of Siemens electric

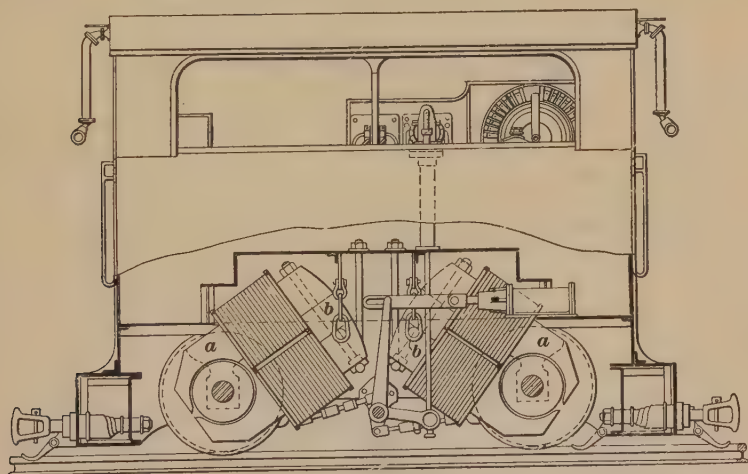


FIG. 1

locomotive used on that line. There are two driving axles, on each of which a motor armature is directly mounted. The motor frame is supported partly by gunmetal brackets *a* on the axles, and partly by means of links from the frame of the locomotive at *b*. By these means the weight of the field magnets and motor frame is partially supported by springs.

The Central London Railway when it was first started used locomotives fitted with 200-horsepower gearless motors, but owing to the vibration which they caused they were replaced by geared motors, and eventually the locomotives were done

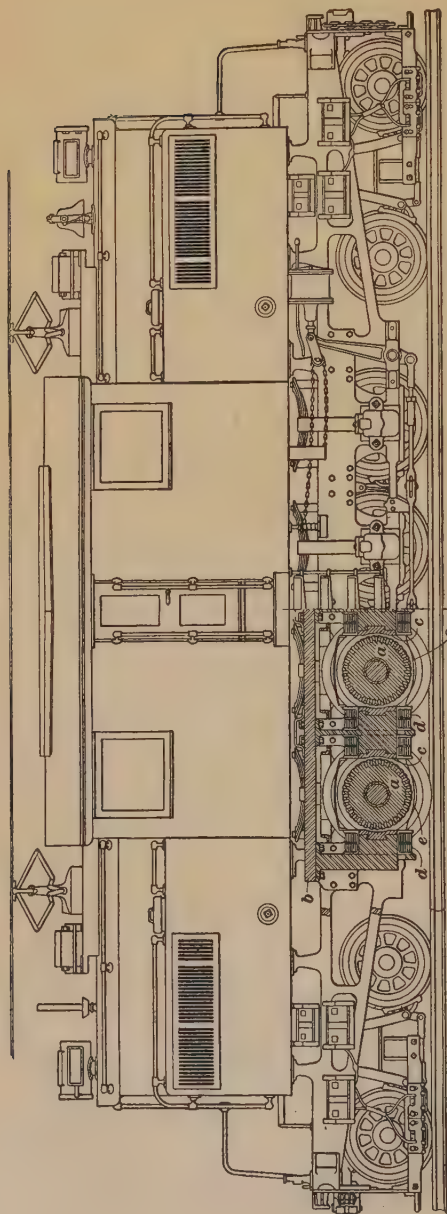


FIG. 2

away with altogether and motor coaches fitted with geared motors were adopted.

6. Locomotive With Bipolar Motors.

A view of an electric locomotive fitted with bipolar motors is shown in Fig. 2. Two of the motors are shown in section while the remaining parts of the illustration show the general appearance of one side of the locomotive. The motor armatures *a* are mounted directly on the driving axes, while the field frames *b* form a part of the locomotive under-frame and carry the pole pieces *c* and field coils *d*. The pole shoes are only slightly curved and the air gap is large, so the armature can move vertically between the pole pieces without touching. This provision is necessary because the motor frames are spring-mounted, while the

armatures must follow every movement of the axle. A brass screen *e* is fixed between the field poles below the armature to protect it from cinders and pebbles which might be picked up from the roadbed.

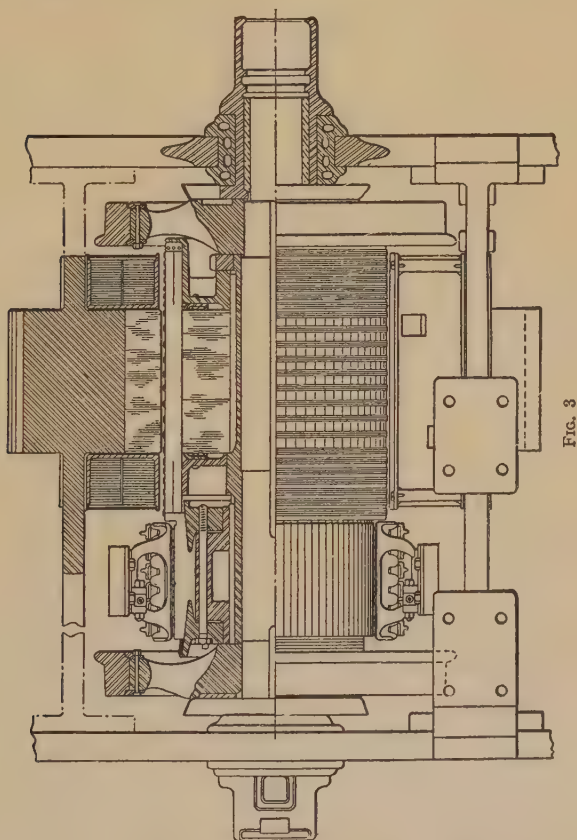


FIG. 3

7. A top view, partly in section, of one of the motors of the bipolar locomotive previously described is shown in Fig. 3. The armature stamps are mounted on a cast-steel spider, and the commutator is built up on a separate spider that is keyed to the armature. After the armature is completed it is pressed tightly on the driving axle after one wheel has been put in place. The brush holders are supported on a frame carried by

the journal-box, and thus always have a fixed position relative to the commutator. This construction is necessary in order to prevent sparking and flashing at the brushes.

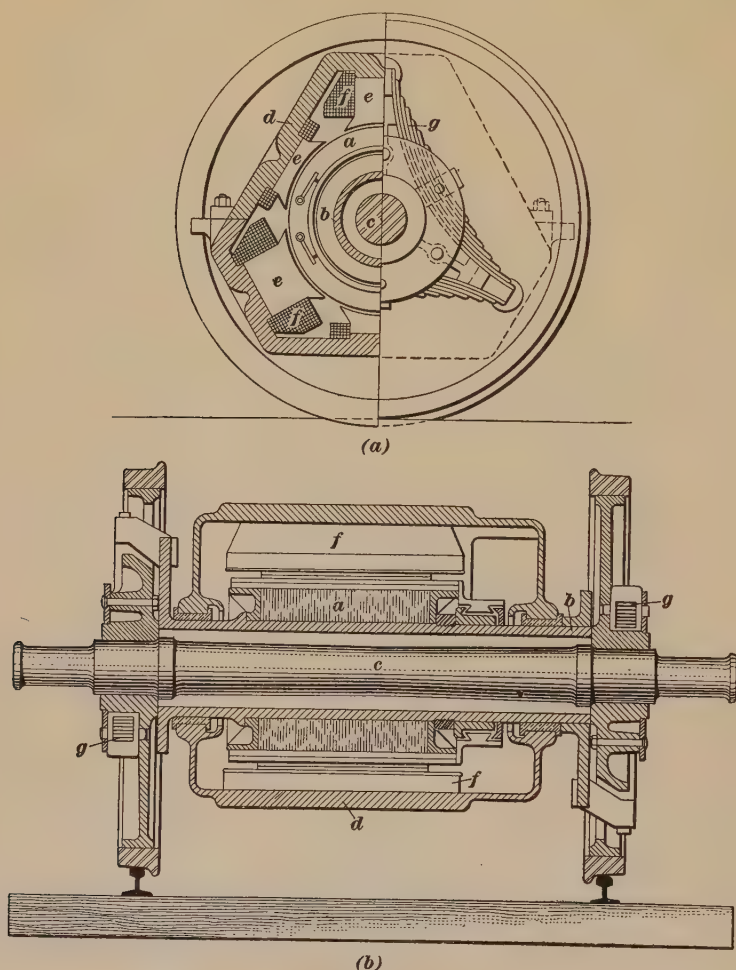


FIG. 4

8. **Example of Sleeve-Mounted Motor.**—Cross and longitudinal sectional views of a sleeve-mounted motor are shown in Fig. 4 (a) and (b). The armature *a* is mounted on a sleeve *b* having the

main axle *c* inside, a certain amount of play being allowed. The frame of the motor *d* is supported on the sleeve and carries the poles *e* on which are the field coils *f*. The sleeve is connected to the track wheels through the leaf springs *g*, so that the entire motor is borne on springs, thus reducing the shock to both track and motor.

9. Locomotives Fitted With Coupling Rods.—It is now usual to fit large electric locomotives with coupling rods, so that the motors can be raised well above the axles where there is plenty of room, thus securing better ventilation and making possible the installation of larger motors than can be used otherwise. The side rod also raises the centre of gravity of the locomotive and permits the motor to be mounted on the spring-borne frame, so that the wear and tear on the track is very much reduced,

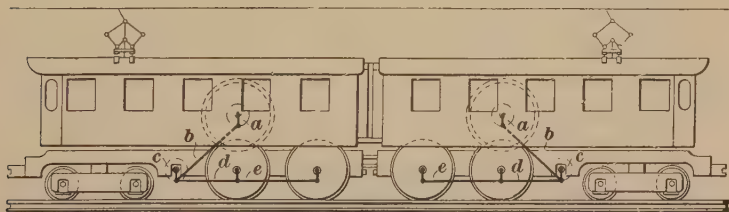


FIG. 5

and, also, the motors can be easily cared for. The raising of the centre of gravity is a decided advantage, especially if a locomotive is to run at high speed round curves. A train tends to move in a straight line, and when rounding a curve it exerts a heavy pressure on the outer rail due to the centrifugal force. If the centre of gravity is low, this force tends to move the rails out of position; but if the centre of gravity is high, there is a tendency to overturn the locomotive, thus making the treads of the wheels and rails take the pressure and relieving the flanges and reducing the side thrust on the rails.

10. A 4,000-horsepower direct-current locomotive which is divided into halves, each fitted with a 2,000-horsepower ten-pole 600-volt motor provided with forced ventilation, is shown in Fig. 5. The motors are supported on the main spring-borne

frame of the locomotive and are connected to the 68-inch diameter track wheels by means of cranks and connecting-rods.

The armature shaft of each motor is provided with cranks *a* at each end, the cranks at opposite ends of the shaft being placed at an angle of 90° to each other. Each crank is connected by means of a connecting-rod *b* to a shaft *c* which is carried by the locomotive frame, so that the distance between its centre and the centre of the motor shaft is fixed. Connection to the cranks on the driving wheels is made by coupling rods *d* and *e*. It is possible to completely counterbalance the weight of the cranks and connecting-rods, because the motion at each end of each connecting-rod is rotational, and thus do away with any pounding of the track. With a steam locomotive, it is not possible to balance the reciprocating parts by counterweights on the driving wheels. The centre of gravity of this locomotive is about 80 inches above the rails, or practically the same as for a steam locomotive, so that it takes curves easily. The maximum tractive effort of 60,000 pounds is sufficient to start a train weighing 550 tons, and the normal speed is 60 miles per hour.

GEARED MOTORS

11. Gearing.—Chain gearing has been used for some of the smaller locomotives for industrial work, and it has the advantage of enabling the motor to be wholly spring-borne, but it is not suitable for large locomotives or for motor coaches because of the first cost and wear and tear. Double helical gear-wheels give very quiet running when the teeth are machined and are very strong, but they also are very expensive. The standard gearing for railway motors is therefore a pressed fluid-steel pinion meshing with a cast-steel wheel, both having accurately cut teeth. The gear ratio seldom exceeds 5 to 1, and a peripheral speed of 3,000 feet per minute should not ordinarily be exceeded.

12. British Thomson-Houston Geared Motor.—A cross-sectional view of a B.T.H. (British Thomson-Houston) 200-horse-power, geared, heavy-traction type motor is shown in Fig. 6. The bearings *a* and *b*, which project under the end connections

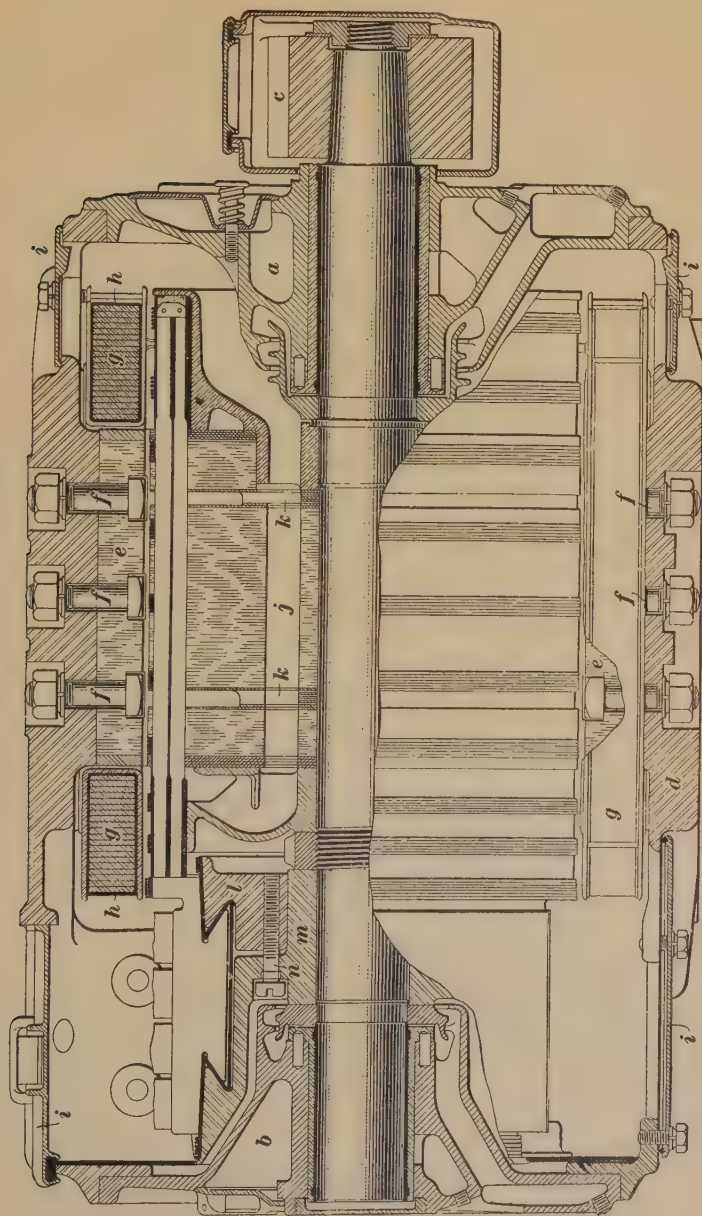


FIG. 6

and commutator hub in order to save space, are carried by the circular end plates, which are securely bolted to the motor casing *d*. The pinion *c* is fastened to the shaft by means of a key and locknut. The shaft is tapered in order to facilitate the removal of the pinion when necessary. There are four laminated poles *e*, two of which are shown, each bolted to the frame by three bolts *f*. Each pole is surrounded by a field coil *g*, which is made up of copper strip insulated with asbestos, so that it can withstand a high temperature without injury. The space occupied by the strip winding is much smaller than would be required if the coil were wound with round wire. It is necessary to insulate thoroughly each coil from the frame, as indicated by the heavy lines *h*. Openings into the casing for purposes of inspection and for adjusting the brushes are provided with covers *i* held in place by bolts. The armature core is provided with ventilating channels, one of which is shown at *j*, near the shaft, and radial ducts *k* pass from the channels to the outside of the core. The commutator boss is made in two parts *l* and *m*, the latter arranged to overhang the bearing *b*; the two parts are held together by bolts *n*.

13. Removal of Armature.—As the casing of the motor is cast in one piece, the armature must be inserted and removed by taking off one of the end plates. In order to facilitate the

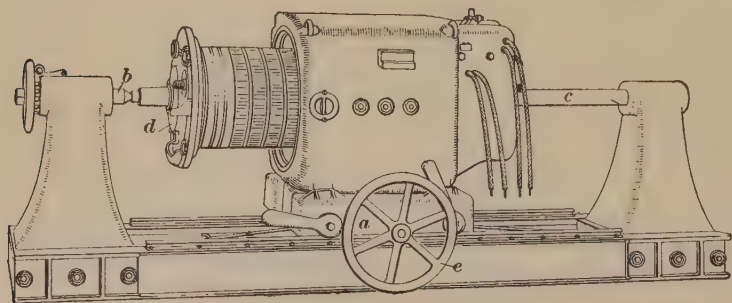


FIG. 7

removal of the armature for repair a special stand, as shown in Fig. 7, is provided. The motor casing is placed on a sliding base *a* and the armature shaft is placed between centres *b* and *c*.

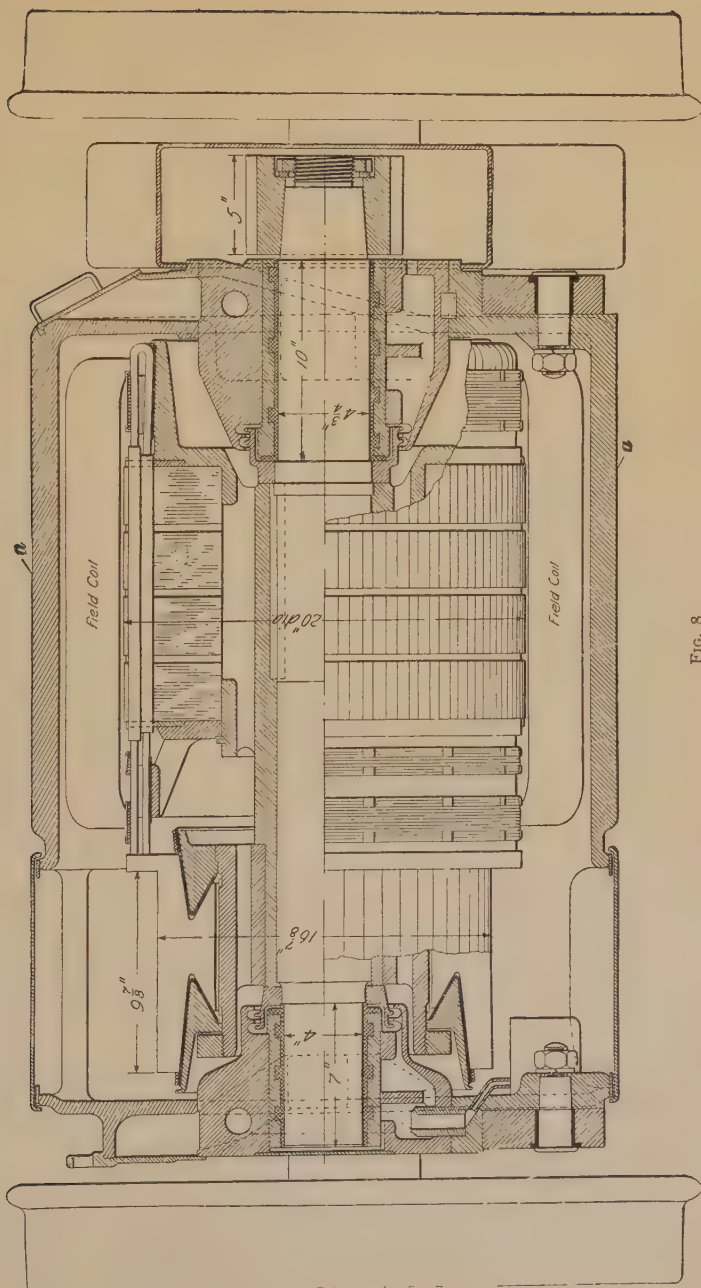


FIG. 8

After the end bearing plate *d* has been unbolted, the motor casing can be moved to the right by turning the hand wheel *e*.

14. Westinghouse Geared Motor.—A sectional view of a Westinghouse railway motor, which can deliver 200 horsepower for 1 hour without overheating, is shown in Fig. 8. The frame, or casing, *a* is made in two parts, and the four poles are arranged diagonally instead of vertically and horizontally, as in the large British Thomson-Houston motors. The armature is provided with ventilating ducts, and the casing with inspection openings fitted with covers.

15. Siemens-Schukert Commutating-Pole Motor.—The greater efficiency of transmission possible when high voltages are used

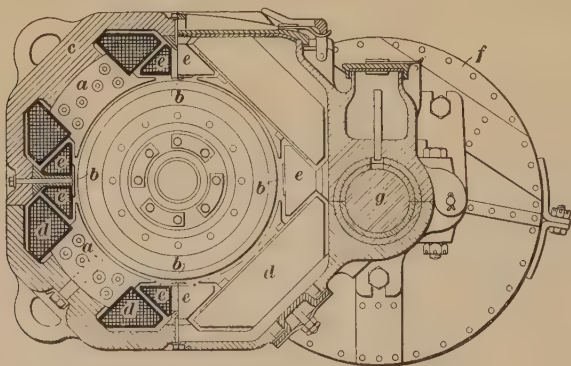


FIG. 9

has led engineers to consider the application of high voltage to direct-current railway motors. This introduces two important difficulties: (*a*) it increases the possibility of a breakdown of insulation, and (*b*) it increases the liability of flashing over between the brushes on the commutator. The first of these difficulties is overcome by providing extra-quality insulation of sufficient thickness, and the second is in some cases minimized by the employment of commutating poles.

Fig. 9 shows a section through a 1,000-volt Siemens geared motor of 130 horsepower. The four main poles *a* are laminated, but the commutating poles *b* are solid, slots being made in the ends to reduce eddy currents. All the pole pieces are bolted

to the frame *c* of the motor, which is cast in halves. The windings *d* and *e* of the main and commutating poles, respectively, are suitably shaped in order to make the best use of the space available; the windings of the commutating poles are permanently in series with the armature. The gear-case is shown at *f* and the locomotive driving axle at *g*.

ARMATURE BEARINGS

16. Plain Bearings.—The bearings of railway motors must be arranged to be as nearly dust-proof as possible, and the system of lubrication must be simple and effective. For the sake of simplicity, plain bearings, such as are shown in Figs. 6 and 8, are used on many railway motors. Oil, and not grease, is almost invariably employed as lubrication. A common form is the wick type, in which oil is fed by the capillary action of the wick on to the top of the journal and along which it is carried by grooves in the bearing bush. Pad lubrication is also largely used; two pads of wool or cotton-waste in the oil chamber press against the journal at points somewhat below the horizontal diameter; the oil is thus evenly distributed without the aid of grooves.

17. Ring-Oiling Bearing.—The lubrication of the Dick-Kerr railway motors is effected by means of oil rings similar to those used for dynamo bearings. The armature bearing boxes are solid castings entirely independent of the main motor frame. The rings dip into the oil contained in a chamber below the axle, and large drain channels are provided to carry away any oil which may be thrown out of the chamber or bearing. Oil throwers prevent oil from creeping along the shaft to the windings. After the bearings have been filled with oil they will run for a fortnight without attention, although it is good practice to have a regular system of oiling once a week.

MOTOR SUSPENSIONS

18. Necessity for Spring Suspensions.—The four-wheeled trucks fastened under each end of a locomotive or motor coach by means of a swivel bolster, and usually called **bogies**, require to be

much stronger in electric rolling stock than for steam working. This is because they have to carry the motors and other electric equipment, and considerable stresses are set up by the direct weight and the torque produced by turning action of the motors. In order that the torque of the motors may be transmitted to the driving wheels, it is essential that the frames of the motors be properly supported on the truck and prevented from turning. One side of a geared motor is always supported by the axle, and the other side is spring-borne. The two most widely used methods of suspending railway motors are, respectively, the *nose suspension* and the *cradle suspension*, and these suspensions are modifications of the styles used on tramcars.

19. Nose Suspension.—In many instances, the motor casing is provided with a projecting lug, or nose, at the side opposite

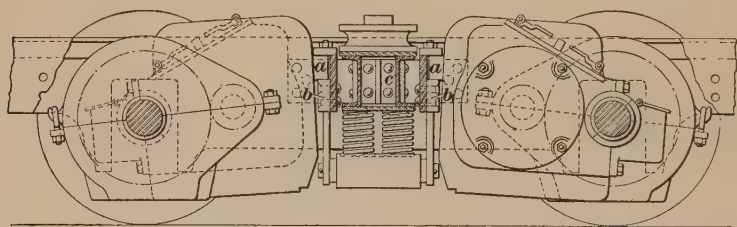


FIG. 10

to that carried by the axles. The projection, or nose, is supported in a suitable manner, and this type of suspension of the motor is called the *nose suspension*. A view of a bogie carrying two motors provided with nose suspension is shown in Fig. 10. Each motor has a nose *a* which fits into a bracket *b* on a bar which is supported from the spring-borne bolster *c*. A part of the weight of the motor is thus carried on springs.

20. Cradle Suspension.—When a motor casing is supported by bars or a frame passing underneath, or attached to lugs at the sides, the motor is said to have a *cradle suspension*. In the Baldwin-Westinghouse cradle suspension shown in Fig. 11, the motors are hinged to the axles *a* by bearings in the ordinary way. Between the axle bearings on each motor case is a projection *b* supporting a spring *c* from which hangs a bolt connected

to a transverse beam *d*. The two beams *d*, *d* form the end members of a rectangular cradle having side members *e*. On each motor there are two forked projections *f*, one situated under each armature bearing. These projections rest on and are bolted to the longitudinal members *e* of the cradle. The motors are supported directly under the armatures; this reduces the stress on the motor casing and the pressure on the bearings. The weight of the motors draws down the cradle and compresses the springs *c*, *c*. The light spring *g* under the projection *b* on the motor frame is to damp out any tendency of the motor to vibrate up and down due to inequalities in the track.

21. Axles.—As the driving axles of electric locomotives and motor-driven coaches directly support part of the weight of the

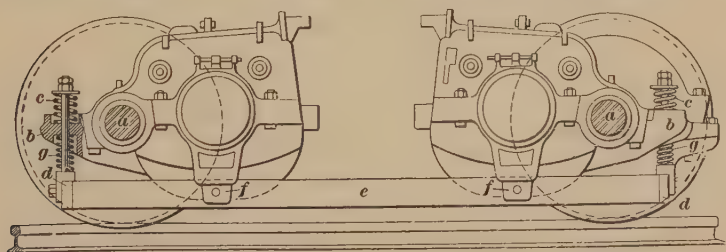


FIG. 11

motors, and are, in addition, subjected to a twisting moment, it is necessary that they be made of larger diameter than the axles of trailers.

The motor coaches of the Central London Railway have driving axles $5\frac{1}{4}$ inches in diameter, and the axles of the trailers have a diameter of $4\frac{3}{8}$ inches, the measurements in both cases being taken at the centres of the axles. The motor coaches on most of the other electric railways in London have driving axles 6 or $6\frac{1}{2}$ inches in diameter, while the axles of the North Eastern Railway locomotives are 7 inches in diameter at the centres.

MOTOR COACHES

22. Central London Railway Coach.—Not only are the bogies for electric railways heavier than those in use on steam railways, but the underframes of the motor coaches are also heavier.

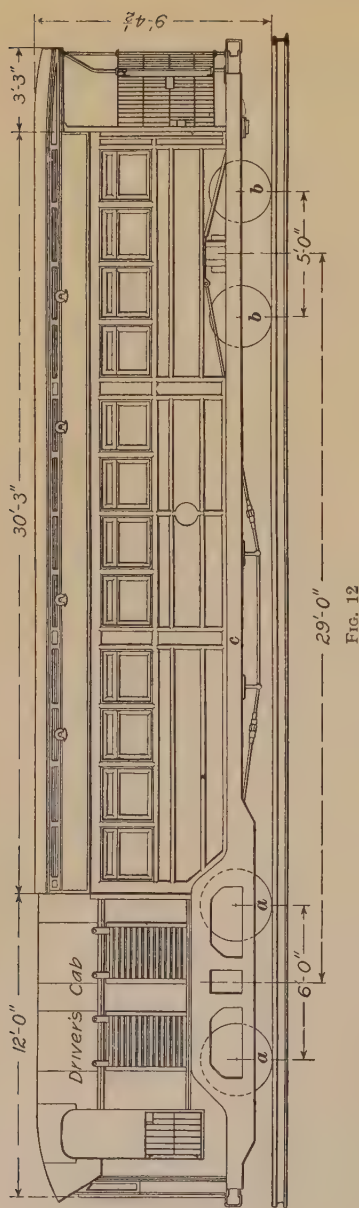


FIG. 12

This is necessitated by the additional weight which they have to carry, due to the cables, contactors, reversers, resistances, and to the modifications to prevent fire in case of a short circuit. With the exception of these, motor coaches for surface electric railways do not differ widely from those in use on steam railways; but for tube railways, as space is very limited, there are many differences in design. For example, the trailer coaches of tube railways have the end sections fitted with longitudinal seats, and under the seats the structure is cut away to leave room for the tops of the track wheels. This is not possible in motor coaches, because of the space occupied by the motors, and therefore the floor level is raised in the driver's compartment at the end of the coach. This construction is shown in Fig. 12, which is an outline of a motor coach used on the Central London Railway. The driving, or motor, end is shown at the left, the driving wheels being indicated at *a, a*. The other end of the car is carried on a trailer bogie, the wheels being marked *b, b*. The longitudinal girder *c* of the underframe is straight at the

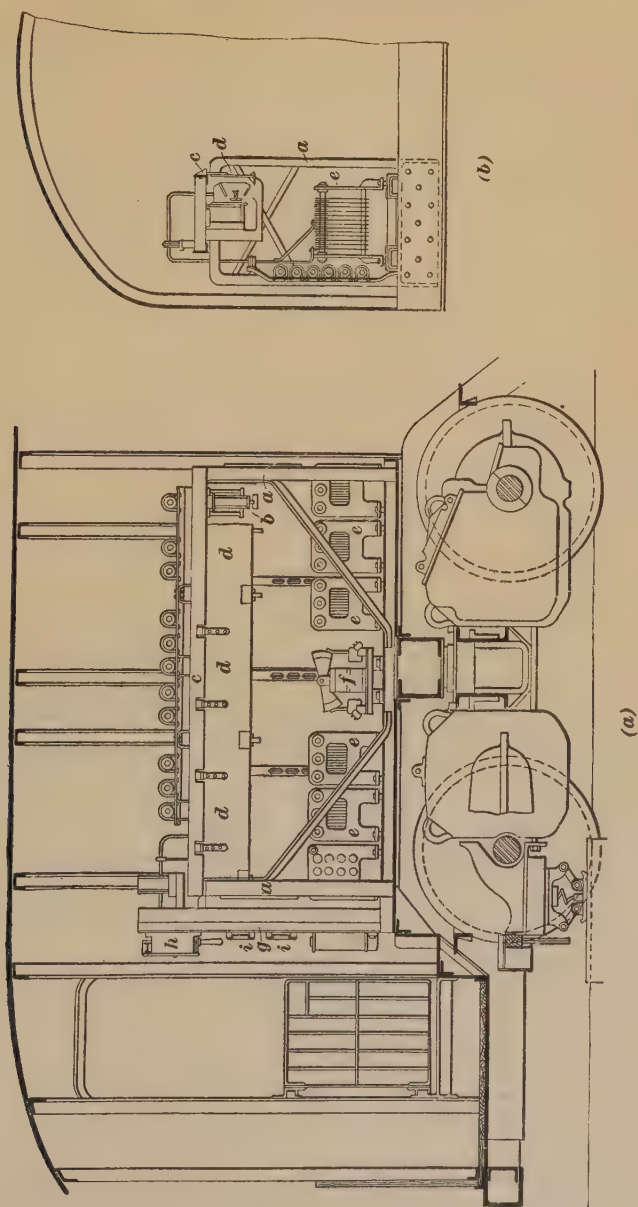


FIG. 13

trailer end, but is curved upwards at the motor end. The longitudinal girders support the cross-members of the underframe, and the floor level in the driver's cab is raised sufficiently to clear the motors.

23. Arrangement of Driver's Cab.—In many cases part of the control apparatus, such as the electromagnetic switches, or contactors, etc., are placed under the body of the coach, but in other cases the whole of the control apparatus is concentrated in the driver's cab. Thus, in the motor coach shown in Fig. 12, the cab contains the master controller, contactors, resistances, and reverser; the main switch and fuses; the switches and fuses for the compressor and lighting circuits; the compressor, air reservoirs, sand box, and tool chest; the air brake, operating valve, whistle, sand cocks, hand-brake, ammeter, voltmeter, and air gauge.

Fig. 13 (*a*) and (*b*) shows the arrangement of the apparatus on the contactor-frame side of the cab of a Central London Railway motor coach. The frame *a* is made of steel angle bars and supports the contactors *b*, which are bolted directly to the top bar *c* of the frame. The shields *d* in front of the contactors are for the purpose of protecting any person, passing the contactor frame, from the effect of the arcs which are formed when a contactor opens. Below the contactors are the resistances *e* and the reverser *f*. At the forward end of the frame *a* is the switch panel *g* containing the main switch *h*, fuses *i*, and other hand-operated switches. A similar arrangement of apparatus is adopted on the Great Northern, Piccadilly & Brompton and the Baker Street & Waterloo Railways.

24. Risk of Fire.—Great care has to be taken on tube railways to minimize risk of fire, and one great step toward the attainment of this end was the introduction of all-steel coaches, which are now used on such underground railways. Wood is, of course, necessary for interior furnishing, but it is subjected to special treatment to render it non-inflammable, and the amount of wood used is made as small as possible. In the Central London Railway coaches the driver's cab is constructed of steel throughout, except the doors in front of the driving platform, which are

of teak. The space between the passenger compartment and the rear bulkhead of the cab is packed with asbestos, and the end panelling of the passenger compartment is made up of *uralite*, which is a special fireproof sheathing, veneered with sycamore. On the Great Northern, Piccadilly & Brompton Railway the coaches are lined with asbestos millboard covered with a veneer of mahogany less than $\frac{1}{16}$ inch thick.

CURRENT COLLECTORS

COLLECTORS FOR CONDUCTOR RAILS

25. General Types of Collectors.—On many electric railways the negative, or return, conductor of the circuit is formed by the track rails, and an insulated third rail is the positive, or feeding,

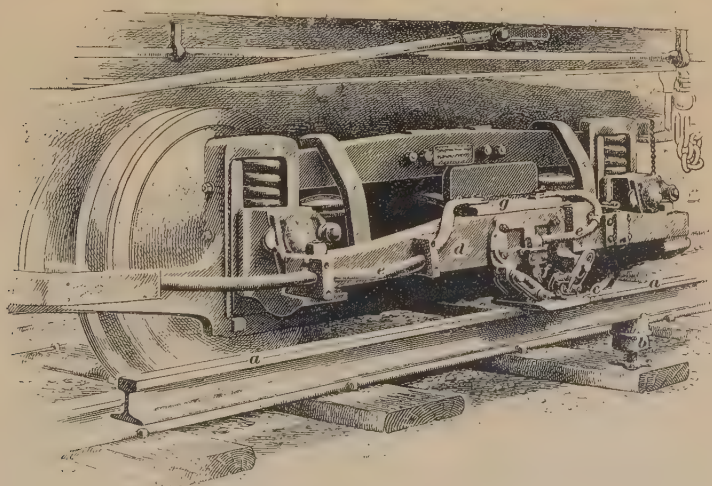


FIG. 14

conductor. On other railways, a fourth conductor rail, either alone or assisted by the track rails, forms the return circuit. For each of these rails sliding contacts, or *collector shoes*, are necessary. On the other hand, some railways, especially those

of the industrial type, take current from overhead trolley wires, the collector in this case being either a trolley wheel or a sliding bow. Some of the small electric locomotives for factory and mining work have a grooved gunmetal shoe pressing against the under side of the trolley wire.

26. Arrangement of Collector Shoes.—A general view of a positive conductor rail *a* supported on insulators, one of which is shown at *b*, and having a collector shoe *c* resting on it, is shown in Fig. 14. The shoe frame is suspended from a wooden beam *d*, which is attached to the axle blocks. A terminal piece on the shoe frame has a cable *e* connected to it and a flexible-copper

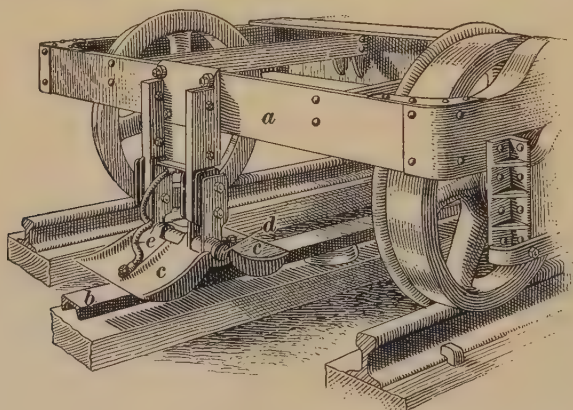


FIG. 15

connection *f* between it and the shoe *c*, so that current is carried direct instead of through the suspension links. The fuse *g* is for the purpose of cutting off current in case of a short circuit. Some of these collectors carry very large currents; for example, on the Liverpool & Southport line, a train weighing 144 tons requires about 2,400 amperes during acceleration. Also, the locomotives of the Pennsylvania Railway are fitted with two 2,000-horsepower motors, each of which requires 2,900 amperes when running at full load.

27. Collector on Liverpool Overhead Railway.—Although it has been superseded by other types, the collector shown in

Fig. 15 is very effective and simple. The shoe is suspended from a transverse beam *a* of the motor truck, and, of course, in this position it is only suitable for a conductor rail *b* laid between the track rails. The collector shoe consists of two parts *c, c* hinged at *d* and provided with flexible conductors *e* to carry the current to the shoe support. This type of collector has been used on the Liverpool Overhead Railway.

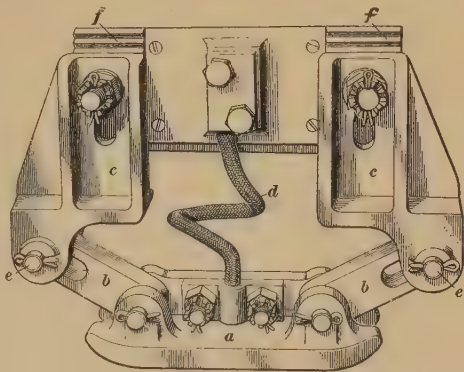


FIG. 16

28. Link-Suspended Collector.—The collector shown in Fig. 16

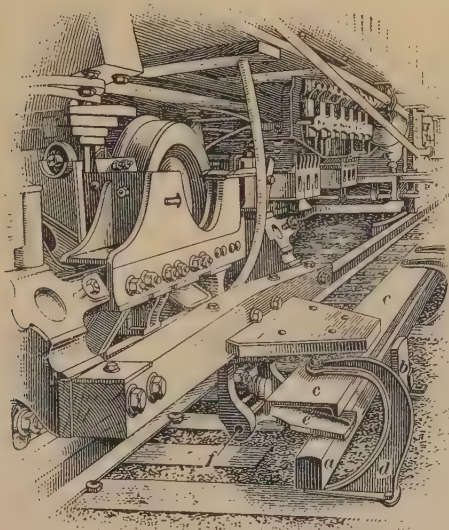


FIG. 17

is known as the **link-suspended type**, and it is the one most used in Great Britain. The shoe *a* is of cast iron, and it is suspended by steel links *b* supported from a cast-steel framework *c*; the flexible cable *d* takes current direct from the shoe to the framework, so that it does not have to pass through the hinge pins *e*. The corrugated surfaces *f* are for the purpose of adjusting the height

of the shoe to allow for varying diameters of the track wheels as

they wear down and at the same time to give general rigidity to the collector-shoe frame. There is no spring to force the shoe down; as its own weight is sufficient to ensure good contact.

29. Ice on Conductor Rail.—The guards over the third rail are to prevent workmen from coming in contact with the live conductor, and also to protect the third rail from snow and ice. When the temperature drops below freezing while rain is falling, there is a liability of a thin skin of ice or sleet being formed on the third rail. This does not often happen in Great Britain, but it has given considerable trouble in the United States, because the ice will not conduct current and is difficult to remove.

There are a number of methods for preventing the formation or adherence of ice on the conductor rail; for instance, swabbing the surface of the rail with oil, sprinkling brine or a solution of calcium chloride on to the rail from a tank carried on a special car, and covering

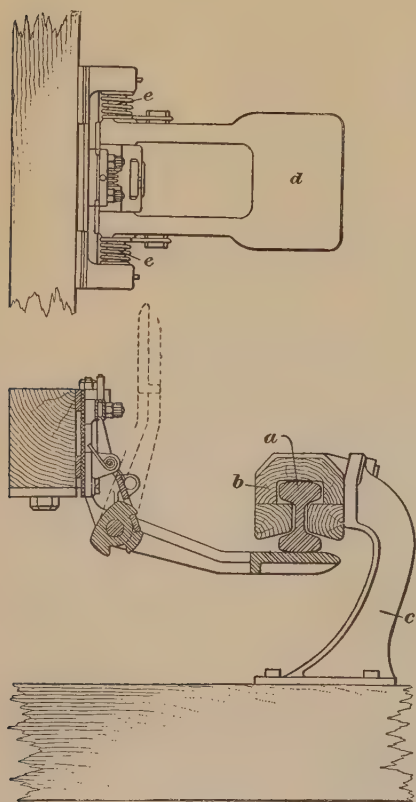


FIG. 18

the rail with an overhanging guard, as shown in Figs. 17 and 18. On many railways, however, the only protection of the conductor rail is by planking laid along each side, and in such cases sleet can form freely on the surface if the climatic conditions are favourable.

30. Collectors for Protected Conductor Rail.—In some installations the conductor rail is protected, and this makes a special form of collector necessary, as shown in Fig. 17. The conductor rail *a* is of rectangular cross-section, so as to be easily manufactured, and is supported on insulators *b*. The protective cover *c* of the conductor rail is made of channel iron and is carried on cast-iron brackets *d*. The collector shoe *e*, hinged at *f*, projects over and rests on the conductor rail. The shoe is light in weight, so a spring is provided to give the necessary pressure between the shoe and the rail.

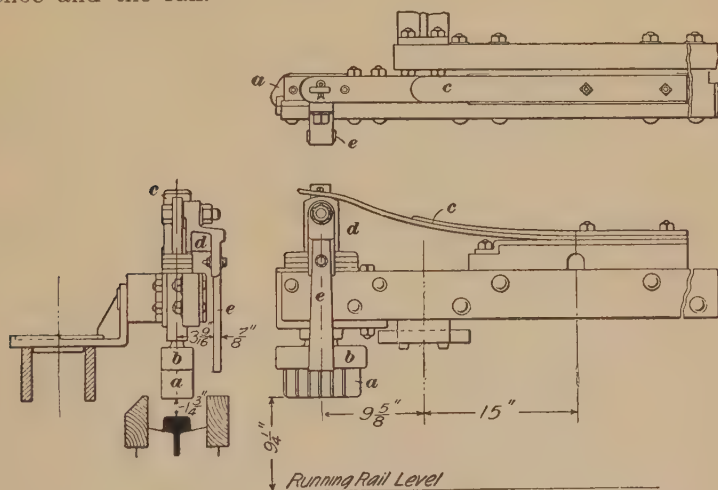


FIG. 19

31. Under-Running Collectors.—Side and top views of a special form of collector shoe are shown in Fig. 18. The conductor rail *a* is suspended from insulators *b*, which are clamped to cast-iron supports *c*. In order to secure unbroken contact the collector shoe *d* must be pressed up against the bottom of the rail. The necessary pressure is secured by the coiled springs *e*, which are shown in the plan view.

32. Sleet Brush.—Sleet brushes are frequently used to remove the ice from the rail, and Fig. 19 shows top, end, and side views of the type of brush or scraper used on the New York Elevated Railway. It consists of a number of thin hard-steel plates *a*

cast into a block *b* and having their edges bearing hard against the surface of the rail, the laminated spring *c* giving the necessary pressure. In order that the steel plates shall not catch on the rail joints they are set diagonally across the rail. A cam *d*

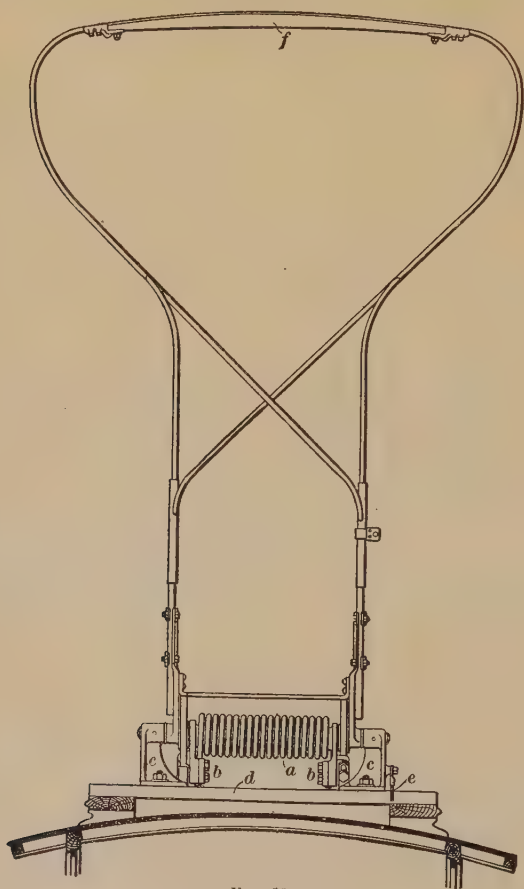


FIG. 20

controlled by the arm *e* is provided to hold the brush off the rail when it is not required. One of these brushes is placed near each contact shoe on each car, and where the trains run at short intervals the formation of ice can generally be kept in check.

COLLECTORS FOR OVERHEAD CONDUCTORS

33. Bow Collector.—The sliding, or bow, collector, which has been much used on tramways, was first introduced on the Continent by Siemens and Halske. Even at the comparatively low speeds of tramcars, the bow collector shows some advantages over the trolley wheel, but for high speeds and heavy trains the bow is in every way considered as superior to a wheel, as it cannot run off the trolley wire, has no tendency to *chatter*, and requires but little attention. A modern type of bow collector suitable for a railway is shown in Fig. 20. The bow slants back from the vertical position when pressed against the under side of the trolley wire, and the steel spring *a* is wound tighter or unwound according to the direction in which the bow is bent over. The ends of the spring are fixed to brackets *b*, one or the

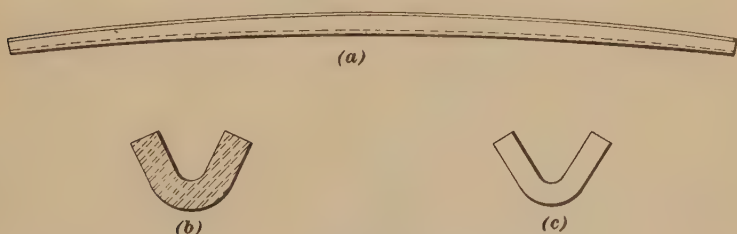


FIG. 21

other of which bears against a projection on one of the fixed brackets *c* when the bow is moved either way from a vertical position. The fixed brackets *c* are supported on a plate *d*, carried on the top of the motor coach, and insulated from it. Current is led away to the motors by the cable *e*.

34. Sliding Strips.—The sliding, or contact, strip *f* at the top of the bow collector, Fig. 20, is made of aluminium, as the lightness of this metal enables the weight and inertia of the collector to be so reduced that a comparatively small upward pressure is sufficient to cause the bow to follow inequalities in the height of the wire. The contact strip shown at (a) in Fig. 21 contains a deep groove filled with grease for lubricating the trolley wire and thus making the motion of the bow noiseless and reducing

wear on the wire. The metal is thicker in the middle than at the ends, as shown by section (*b*) and end view (*c*), to allow for the greater wear near the centre of the bow. Under ordinary circumstances, the life of a contact strip is found to be 30,000 car miles, although higher figures have been obtained.

35. Reversible Bow Collector.—The bow collector described in the previous article is reversed at the end of each journey by suspending the trolley wire at such a height that the bow stands nearly upright. Then, when the motor coach starts off

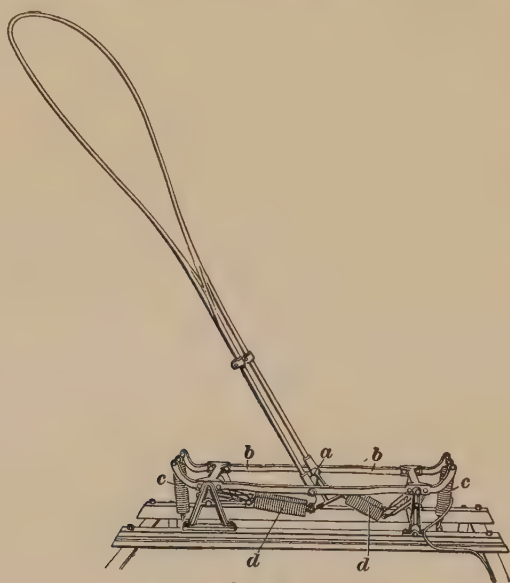


FIG. 22

in the opposite direction, the bow automatically lays over at the required angle because of the friction between the trolley wire and contact strip. Of course, in locomotives used for shunting, it is necessary that the bow should reverse itself at any point on the line, instead of only at the reversing points where the height of the trolley wire has been specially increased. The Siemens-Schukert bow, shown in Fig. 22, has been specially designed to suit the condition. The horizontal axle *a* on which the bow rotates is carried on double levers *b* held in position by

springs *c*. When the vertical pressure on the axle increases, as it does when the direction of motion is reversed, the axle moves downwards and the bow reverses itself automatically. The bow is pressed against the trolley wire by two pairs of springs *d*, which are attached to any extension of the bow frame below the axle *a*.

36. Bow Collector for Large Currents.—For very large currents the type of collector shown in Fig. 23 or Fig. 24 is used. In the collector shown in Fig. 23 the short bow *a* is pivoted at *b*, and the framework *c*, pivoted at *d*, is capable of being raised and

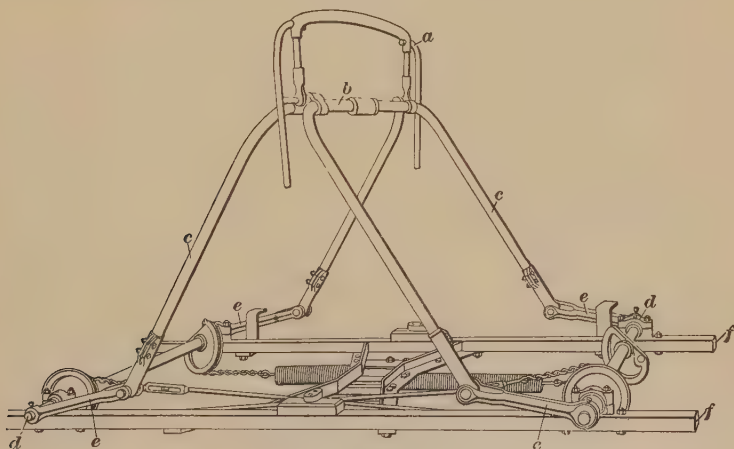


FIG. 23

lowered by the driver, so as to bring the bow into or out of contact with the trolley wire. As shown in the illustration, the collector is in the raised position; when lowered, the cranks *e* are below the horizontal bars *f*. This lowering is required not only to reverse the bow, or break contact with the trolley wire, but it also has to be done when passing under bridges where the trolley wire is lower than in the open.

37. Air-Operated Collector.—Electric locomotives which require large currents are in some cases fitted with the type of collector shown in Fig. 24. This collector is of very heavy

construction, and is intended specially for overhead conductor

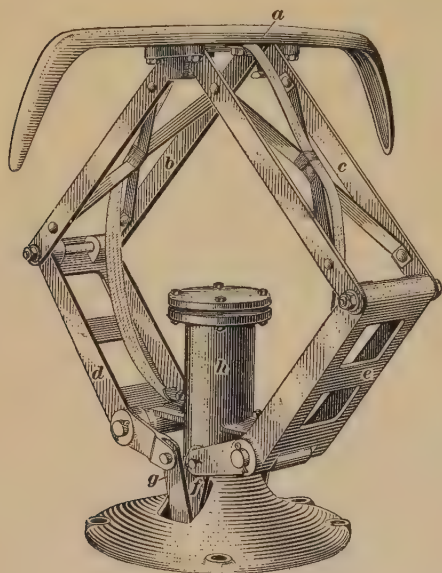


FIG. 24

rails in tunnels or storage yards. The bow collector *a* is supported by the arms *b, c, d, e*, the lower arms *d* and *e* being connected by the strips *f, g* to the crosshead of a piston rod working in the air cylinder *h*. The air cylinder is provided with supply pipes so that compressed air may be admitted above the piston, thus driving the crosshead down and raising the bow *a*. In order to lower the collector, it is only necessary to release the air above the piston and the arms

will collapse until the bow rests on the top of the cylinder.

SYSTEMS OF CONTROL

GENERAL REQUIREMENTS OF CONTROL SYSTEMS

WIRING CONSTRUCTION

38. **Board of Trade Regulations.**—The Board of Trade have made a number of rules regarding the precautions which must be taken in the construction and operation of motor-driven coaches and trains. The rules which apply specially to underground railways are as follows:

1. Cars to be constructed of metal; woodwork to be reduced to a minimum and to be non-inflammable. Hard wood must be used in preference to soft. Interior fittings, panels, seats, etc., to be of incombustible material.

2. No main electric cable to be carried through the train, and motors to be placed on the front and rear carriages only. No motor to be situated in the middle of the train.

3. Means to be provided at both ends of every train to enable passengers to alight from the cars in case of emergency. Oil lamps to be carried in every train.

4. India-rubber or other inflammable insulating materials to be avoided as much as possible, and the outer covering of cables to be unflammable material that will not give off smoke.

5. Means to be provided for enabling a driver at any part of the tunnel to put himself into telephonic communication with the adjacent stations.

39. General Arrangement of Wiring.—The electric wiring for motor coaches includes not only the control wires, but also the main power circuits. As the control wires must run from end to end of the train, **coupling cables**, or **jumpers**, which are short lengths of cable having the number of wires necessary for the control circuits and arranged with suitable connectors, must be provided between the various coaches to connect the control systems. If a train is made up of several motor coaches, the feed-wires from the collector shoes are sometimes connected to heavy conductors called **bus-lines**, which run the entire length of the train. The object of the bus-line is to supply all the motors with current, though some of the collector shoes may not be in contact with the supply conductor. For underground railways the Board of Trade will not allow bus-lines, so their use is limited to surface railways. To guard against fire, the contactors are enclosed in fireproof compartments, all the main wiring is run in iron pipes, or conduits, and the outer insulation of the flexible cables must be non-inflammable. In some instances the wiring is contained partly in wooden troughing cased with uralite, as this material is an insulator as well as being non-inflammable.

40. Conduits.—Where wood is used in the body of the car, the conduits may be cleated to the under surface of the body. On underground lines, where all-steel cars are used, the conduits are passed through holes in the transverse beams or are carried by brackets fixed to the under side of the transverse beams or longitudinal girders. Sometimes the conduit is coated with

enamel inside or inside and out. This treatment enables the cables to be easily drawn in, provides additional insulation, and prevents rust. Wherever possible, the conduits are given a slope so that any water that may condense inside drains to a point where it can be drawn off. In order to prevent abrasion of the insulation where the cable leaves the conduit, a collar of rubber or other yielding material is provided.

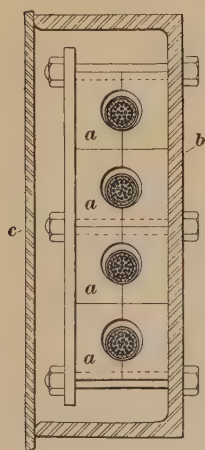


FIG. 25

41. Porcelain Cleats.—On the Great Northern & City Railway the train cables are supported in **porcelain cleats**, as shown in Fig. 25. The cleats *a* go inside the longitudinal members of the underframe *b* of the coach, and the channel is closed by a steel plate *c*.

42. Control Couplers.—All the train wires on a coach are united into a train cable, which is provided at each end of the car with a socket in which there is a plug or pin connected to each train

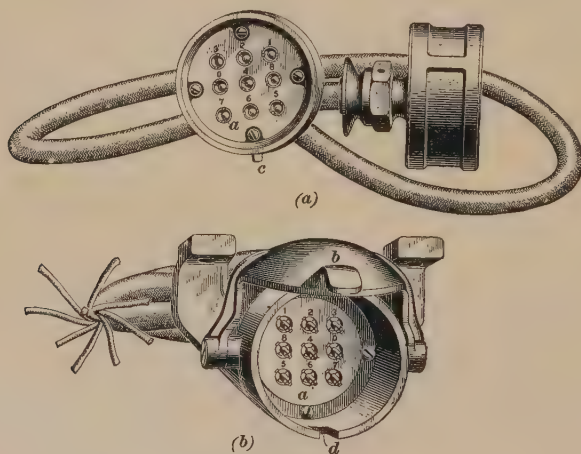


FIG. 26

wire. At each end of each jumper, or **control coupler**, is a plug that fits into the socket on the end of the car cable. In the

plug there is a receptacle at the end of each of the jumper wires, and these receptacles fit over the corresponding plugs in the car-cable socket. A jumper for several wires is shown in Fig. 26 (*a*), and the corresponding socket on the train cable is shown in view (*b*). The receptacles in the jumper plug are shown at *a*, and the pins in the car cable are shown at *a*, view (*b*). To prevent any mistake in the insertion of the jumper, its plug is provided with a projection *c*, which fits into a corresponding gap *d* in the socket. To protect the car-cable socket when not in use, a hinged cover *b* is let down over it.

REQUIREMENTS OF TRAIN CONTROL

43. Connections to Motors.—Just as the motors for tramways and railways were at first very similar, so also the controllers have developed along similar lines in the two cases. The controllers of the form approved for tramway service were therefore adopted for railway working until conditions necessitated radical alterations. Such alterations have not affected the main principle of control, and all the systems about to be described provide for the following operations: (*a*) Motors with resistance are connected in series; (*b*) resistance is gradually cut out; (*c*) motors are connected in parallel, with resistance in series; (*d*) resistance is again gradually cut out.

This method of procedure is, of course, subject to modification where a coach or locomotive is equipped with more than two motors. For example, with four motors the connections may be in the following sequence: (*a*) All in series, (*b*) two sets of two in series, (*c*) all in parallel.

44. Necessity for Multiple Control.—Series-parallel controllers worked by hand are sufficient for small railway systems and industrial locomotives where the currents do not differ much from those which have to be handled on tramways. Heavy railway working, however, calls for special methods of control, as the currents are large and sometimes supplied at high voltages; also in many cases the trains are made up of several motor coaches. It is obvious that, when several coaches in a train are

equipped with motors, the method of control must provide for the management of all the motors from any one point of the train ; also the train must be easily divisible, and it should be possible to add other motor coaches which can be operated with the ones previously in use. These requirements led to the introduction of the multiple-unit system of control, by means of which several coaches, each equipped with motors of sufficient power for its own needs, connected together to make up a train, are governed by a master controller. The master controller causes the electromagnetic switches on each motor coach to operate, thus providing the same connections for all the motors.

45. Reversibility of Connections.—An important requirement in multiple-unit systems is the flexibility of the train, and this has great influence on the design of the wiring. It must be possible to turn any coach or any jumper end for end without affecting the control of any of the units of which the train is composed. When a jumper is reversed there must be no change in the relative connections between coaches ; the connections both to the reverser and to the contactors on each coach must remain as before. On the other hand, when a coach is reversed, the connections to the reverser must be so changed that the reverser operates in the opposite way and the coach will move in the same direction as the rest of the train. At the same time, the connections to the contactors which control the speed must be unchanged. It is therefore necessary to distinguish between the train wires, which are connected to the reverser and thus determine the direction of motion of the coach, and those which make connection with the contactors and control the speed of the motors. For brevity these wires will be referred to as *reverser wires* and *contactor wires*, respectively.

46. Crossing of Contactor Wires.—In practice, the method usually adopted of disposing the wiring so as to attain the objects stated is to cross the contactor wires in the couplers and in the jumpers and to take the reverser wires straight through both without crossing. Fig. 27 illustrates the method, *a* and *b* representing in plan two coaches and *c* the jumper connecting them. To facilitate the distinction between reverser wires and

contactor wires, the former are indicated by letters $d-e'$, $e-d'$ and the latter by numbers $1-1'$, $2-2'$, $3-3'$, $4-4'$, $5-5'$. The effects of the various changes possible in connecting the cars and jumpers are as follows: If the reverser wires $d-e'$ are connected to the positive main through the master controller, then the train may be assumed to move in the direction of the arrowheads marked on the uppermost wires, that is, from right to left.

47. Reversal of Jumper.—If the jumper c , Fig. 27, is reversed, the connections have the appearance indicated in Fig. 28. In

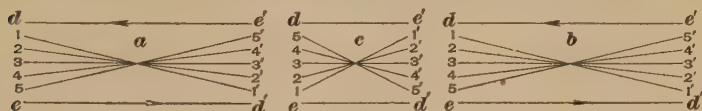


FIG. 27

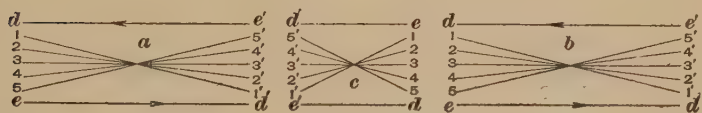


FIG. 28

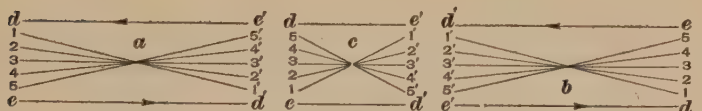


FIG. 29

this case, the connections are identical with those in the previous illustration, and as the contactor wires $1-1'$, $2-2'$, $3-3'$, etc., remain unchanged throughout the train, and the reverser wire $d-e'$ of coach a connects to wire $d-e'$ of coach b , therefore the direction of motion of each coach remains the same. It should be recalled that a lug on the jumper fits into a corresponding slot in the coupler, and thus prevents the jumper from being inserted in any other than in the positions indicated in Figs. 27 and 28.

48. Reversal of Coach.—The effect of reversing a coach is shown in Fig. 29, in which the coach b is turned end for end.

In this case, current is supplied to the wire $d'-e$ on coach b instead of to $d-e'$. As a result the coach moves in the direction of the arrow on the line $d'-e$, that is, in the same direction as the rest of the train, but the direction of motion is toward the end d' , $1'$, $2'$, etc., instead of toward d , 1 , 2 , etc., as shown in Fig. 27. It will be noticed that the contactor connections are unchanged, due to the crossing of the contactor wires on the jumpers and on the coaches.

EARLY MULTIPLE-UNIT SYSTEMS

49. Siemens Mechanical Control.—Among the earliest and simplest of the systems for controlling the motors on a number of coaches was a mechanical method, introduced by Siemens Bros. It consisted of an arrangement of jointed levers extending throughout the whole length of the train, so that the controllers on each motor coach could be operated from the driving end. This method was objectionable because of the mechanical difficulties at the joints between the control rods of the various motor coaches, and was soon abandoned. An electrical method of control presented the best solution of the problem, and is the one invariably used at the present time.

50. Sprague Multiple-Unit Control.—In the first type of the **Sprague multiple-unit control system**, there is on each coach a standard barrel controller actuated through a worm-gear by means of a small pilot motor. The main controller barrels are connected to the worm-wheel shaft by means of a spring, and a cam and pawl are provided so that the controller barrel moves by a succession of jumps, thus quickly breaking the arcs that form at the contact fingers. A number of wires, which are called *train wires*, pass from coach to coach to supply current to electromagnetic switches, which in turn give current to all the pilot motors. The operation of these electromagnetic switches is governed by means of a master controller, which is in the form of a switch with three positions for each direction of running; it also has contacts by which other electromagnets are energized to operate the reversing barrel. In each main controller are the main circuit contacts and seven additional contacts, which

are required for limiting the travel of the controller barrels ; these additional contacts are suitably connected in the pilot-motor circuits. An important feature of the system is the automatic relay, which is an electromagnetic switch having its operating coil in series with one motor. Normally this switch is closed ; but if the motor current rises above a pre-arranged value, the increase of magnetizing current causes the switch to open, thus breaking the circuit of the pilot motor. The pilot motor is also fitted with an electromagnetic brake, which is held off when the motor is running. When the pilot-motor circuit is opened the brake is applied, and further progress of the main controller is prevented till the current in the main motors falls sufficiently to allow the automatic relay to close the control circuit.

51. Operation of Master Controller.—In the *first* position of the master controller all the reversing barrels are moved to their forward or backward positions ; but as the pilot-motor circuits are not completed, the main controller barrels remain in the off-position. In the *second* position of the master controller an electromagnetic switch on each car is closed, and the circuit of the pilot motor is completed through this switch and a contact on the main controller barrel. The pilot motor starts and the main controller barrel is moved forwards at a rate governed by the automatic relay, and when the full series position is reached the circuit of the pilot motor is broken. When the master controller is placed in the *third* position, the pilot-motor circuit is again completed ; the main controller barrel now progresses until the full parallel position is reached.

52. Pilot Motor.—The field magnets of the **pilot motor** are wound with two coils, either of which can be connected in series with the armature. In the operations just described only one of these coils is used. If it is desired to turn the main controller barrel back from any parallel position to the full series position, the master controller is moved back to its second position. This operation opens the pilot-motor circuit, but completes it almost instantly through the second field winding ; the direction of rotation of the motor is thus reversed, and the main controller

barrel is returned to the full series position. If the master controller is moved from any advanced position to the off-position, the main controller barrels will be returned to the off-positions.

53. Necessity for Unit Switches or Contactors.—An arrangement for operating the various main controllers on a train by means of a master controller is quite suitable where the power is moderate, but an ordinary barrel controller for a pair of 100- or 200-horsepower motors would be very large, and suitable arrangements for effectively suppressing the arcs formed when the circuit is broken at the contact fingers of the controller could not be very conveniently devised. Since a controller is in principle simply a collection of switches, the problem has been solved by separating the switches; and this has given rise to various control systems, in which the switches are opened and closed in the desired order by means of electromagnets, each single switch, or **contactor**, having its own magnet. The operating coils of these electromagnets are connected together by means of train wires, which run the whole length of the train and are tapped off at a number of points by connections to master controllers. Such systems are termed **unit switch**, or **contactor**, systems.

SPRAGUE-GENERAL ELECTRIC TYPE M CONTROL

CONTACTORS, REVERSER, AND CONTROLLER

54. Contactor Groups.—A group of contactors is in principle simply an ordinary controller separated into its component parts, but the separation has been accompanied with modifications to suit the practical conditions of working. All contactors are controlled by electromagnets, for although in the Westinghouse system the contactors are actually worked by compressed air, yet the valves governing the supply of air are worked by electromagnets. It is necessary that contactors open and close with minimum *lag*, or loss of time when the operating circuit is closed. There must be sufficient pressure between the working contacts in order that the contact resistance may be small, and there

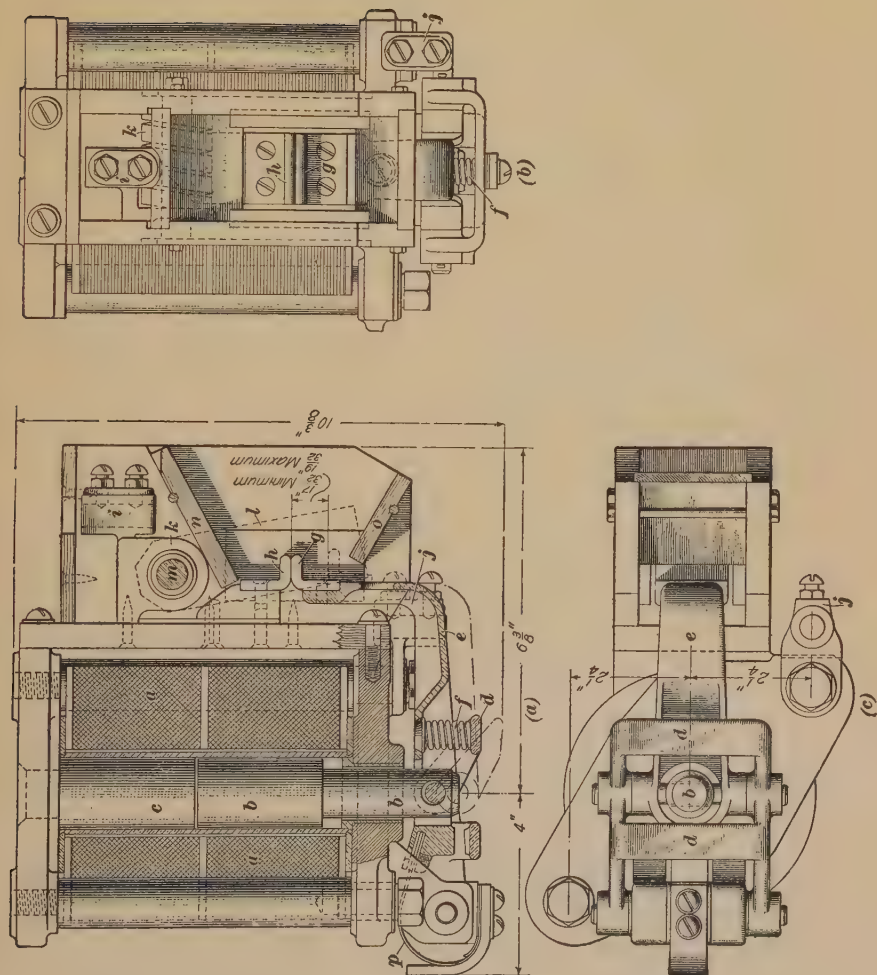


FIG. 30

must also be some device to suppress arcing when the circuit is opened. It is further requisite to construct the contactor in such a way that all parts, especially those most liable to wear, can be easily renewed.

55. British Thomson-Houston Contactor.—One form of contactor used by the British Thomson-Houston and General Electric Companies is shown in Fig. 30, which gives at (*a*) a side-sectional view, at (*b*) a front view, and at (*c*) a bottom view. The operating coil *a* is wound in two sections round the movable core, or plunger, *b* and the corresponding stationary core *c*. On the lower end of the plunger *b* is hinged a frame *d* that presses on arm *e* through spring *f*. Arm *e* carries on its upper end a contact tip *g* that, when the arm is in the position shown, presses against a stationary contact tip *h*, thereby closing any circuit of which they may be a part. One main terminal of the contactor is shown at *i* and the other at *j*. A blow-out coil *k*, consisting of a few turns of heavy bare conductor, is wound round a core *m* to which iron pole pieces *l* are bolted for the purpose of directing a strong magnetic field across the region of tips *g* and *h* and thus suppressing arcing at the contact tips. The arc is driven to the right through a specially provided flue, of which *n* and *o* are the top and bottom walls. The slightly flexible connection *p* is to carry the current from the contact piece *g* to the contactor frame, and thence to the main terminal *j*.

56. The operation of the contactor is as follows: When current from the control circuit passes through the operating coil *a*, plunger *b* is drawn up to the position shown in Fig. 30. At first the frame *d* and arm *e* move together about the pivot, but when tip *g* has come into contact with the stationary tip *h*, further motion of *d* compresses the spring *f*; in this way the contact tip *g* is given a slight rubbing action relatively to *h*, thus ensuring a good contact. The spring also assists the action of gravity in opening the switch promptly and preventing the contacts from sticking when current is cut off from the operating coil.

57. British Thomson-Houston Reverser.—The appliance used in multiple-unit systems for changing the connections to the

motors is called a **reverser**. The reverser is a form of solenoid switch or contactor operated by current from the control circuit through the reversing cylinder of the master controller.

The form of reverser used with the type M system of control is shown in Fig. 31. A cast-iron rocker *a* is hinged at *b*, and on the ends of the beam are two moulded insulation pieces *c*, to which are attached the heavy segments *d*, *d* that carry the main-motor current; segments *e*, *e* are lighter and carry the control current only. Fingers *f*, *f* engage with the heavy segments, and *g*, *g* with the lighter ones. The rocker can be moved through a limited range by means of two solenoids, one of which is shown at *h*; a similar coil is behind *h*, the end of its plunger being shown at *k*. The plungers of the solenoids are connected to the rocker-arm through suitable links, and the movement of the rocker is limited by stops. When coil *h* is energized, the rocker occupies the position shown in the illustration; but when the

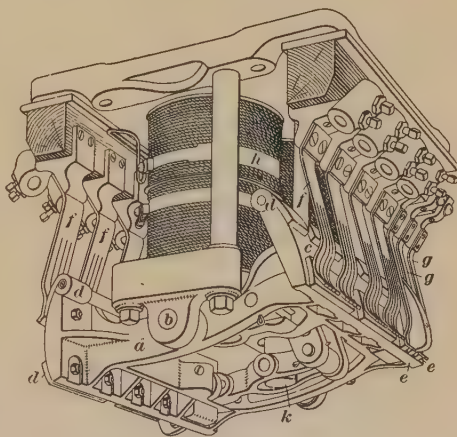


FIG. 31

other coil is energized, the rocker is thrown over to the other position, the left-hand side being pulled toward the base of the reverser and the other side moving down, thus bringing different sets of contacts under the contact fingers. Suitable interlocks make it impossible for both coils to be energized at once. One position of the rocker corresponds to the forward position of the reversing handle on the master controller, and the other to the reverse position.

58. British Thomson-Houston Master Controller.—The master controllers in use with multiple-unit systems of train control

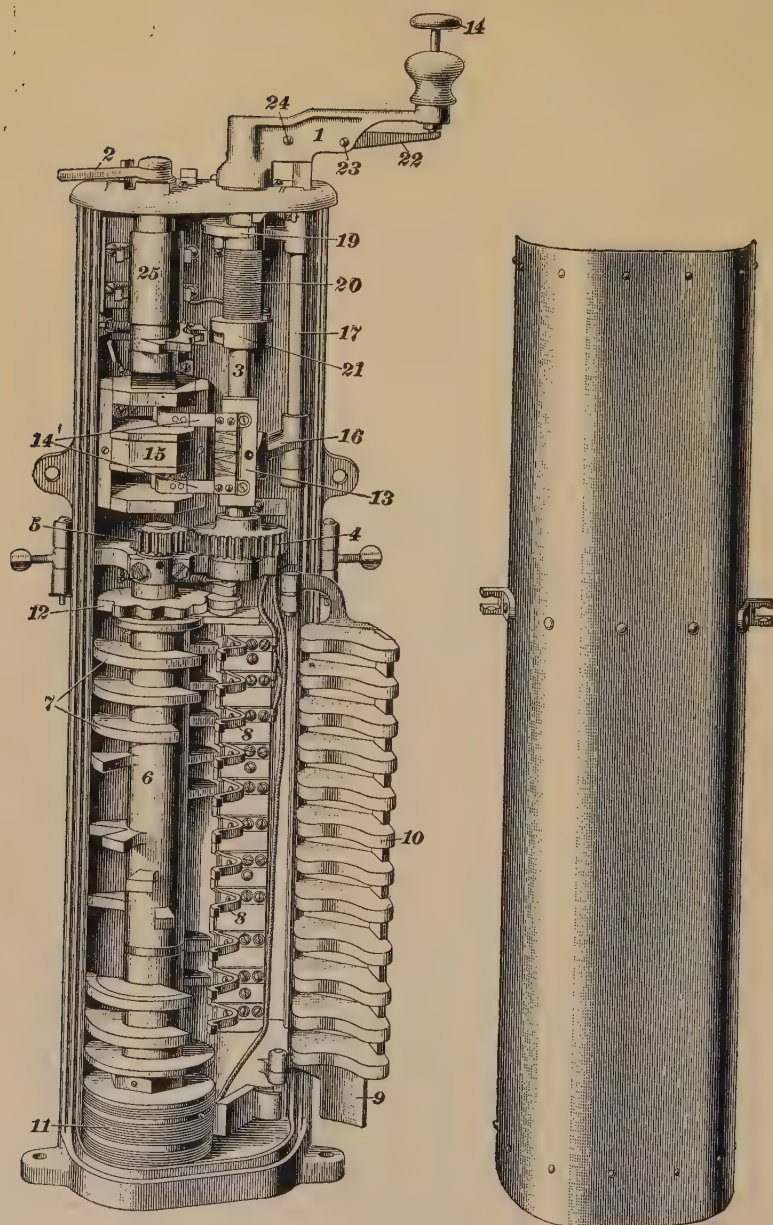


FIG. 32

are smaller than the ordinary hand controller used on tramcars. The master controller carries only the current necessary to operate the various contactors, and the reverser of the main or power-control system and the contacts are therefore not designed for heavy service. A view of a British Thomson-Houston type C6 master controller is shown in Fig. 32. The operating handle *1* is not removable, as on an ordinary controller, but the reverse handle *2* is, and when removed the main shaft is locked so that it cannot be turned. The operating handle turns shaft *3*, on the end of which is a gear *4* that meshes with pinion *5* on the shaft of the contact cylinder *6*. The contact cylinder is constructed in the usual manner, except that the contact segments *7* are considerably narrower than on an ordinary controller, the current handled being comparatively small. Contact segments *7* engage with contact fingers *8*, mounted on a terminal board in the usual manner. The iron pole piece *9* carries the insulating arc deflectors *10* that pass between adjacent contact segments whenever the hinged pole piece is swung into its usual position. All current handled by the master controller passes through the blow-out coil *11* and sets up a magnetic field that suppresses arcing at the contacts. The main cylinder is provided with the usual cam-, or index, wheel *12*, which, in connection with a spring-actuated pawl, gives decision to the notches.

59. Dead Man's Handle.—The C6 master controller contains a safety switch *13*, Fig. 32, not usually found on ordinary controllers; it is provided as a factor of safety in high-speed work. To operate the controller and supply current to the motors, it is necessary for the driver to keep knob *14* depressed; if the knob is released, all power is at once cut off from the motors by the opening of safety switch *13*, irrespective of the position of the operating handle; nor can power be applied to the motor circuit again without first restoring the operating handle to the off-position. Should an accident befall the driver, causing him to release knob *14*, the train will be automatically stopped. On this account knob *14* is sometimes called the **dead man's knob or handle**.

60. Operation of Safety Switch.—Switch *13*, Fig. 32, consists of an insulating block on which are mounted two fingers *14'* connected together by a metallic strip. When the switch is closed, the fingers touch contacts mounted in the recesses above and below the auxiliary blow-out coil *15*, which is encased in insulating material. The insulating block that carries fingers *14'*, *14'* is mounted on the end of an arm *16* fastened to the rock-shaft *17*, which is acted on by a spring that normally holds it in such a position that fingers *14'*, *14'* are swung out from their respective contacts. All the current in the operating circuit has to pass through the safety switch, and unless this switch is closed, the control circuit is inoperative and no current can be supplied to the motors. The movements of the rock-shaft *17* and switch *13* are controlled by a cam *19* that has a notch engaging a short arm extending from the rock-shaft ; cam *19* is mounted loosely on the main shaft. A spiral spring *20* has its upper end attached to *19* and its lower end to collar *21*, which is firmly fixed to the main shaft *3* and rotates with it.

61. If handle *1*, Fig. 32, is turned, without pressing down knob *14*, the main shaft *3* and drum *6* are turned, but cam *19* does not turn, because it is mounted loosely on the shaft and is prevented from turning by the projecting arm on rock-shaft *17*. Under these conditions, therefore, spring *20* merely twists or untwists, and since switch *13* is not closed, the control circuit is inactive. If, however, knob *14* is pressed down before handle *1* is turned, a small dog, or catch, is pressed down and locks cam *19* to shaft *3*. This dog is forced down by means of lever *22*, hinged at *23*, which engages a second small lever hinged at *24* and mounted within the handle. When cam *19* is thus locked to the main shaft, it forces the rock-shaft *17* to rotate through a small angle just as soon as handle *1* is moved from the off-position, thereby closing switch *13* and allowing current to pass through the controller. Spring *20* is placed in position at the factory under considerable tension, so that there is always a tendency for relative movement between cam *19* and collar *21*. When handle *1* is moved round and knob *14* is pressed down, cam *19* is locked to the shaft and hence moves round with

collar 21. There is therefore no twisting action on the spring and no change in the initial tension.

62. After the handle 1, Fig. 32, of the controller has been moved round from the off-position, if the knob 14 is released, the dog engaging cam 19 is released, and 19 is then free to revolve on the shaft independently of the collar 21. As soon as 19 is released, the tension on spring 20 causes it to fly to its initial position, and switch 13 at once opens, thus cutting off all current from the control circuit. Before the catch operated by 14 can be again made to engage with cam 19, handle 1 must be brought back to the off-position, thereby restoring the tension in spring 20 to the original amount. The safety device not only cuts off the current in case of accident to the driver, but it prevents current from being thrown on, unless all operating handles are in the starting position. Other forms of dead man's handle have been brought into operation, in which the release of the handle applies the air brakes besides cutting off current from the control circuits. In Great Britain, this device is especially important, as the Board of Trade do not allow a train to be put in charge of only one man unless some such device is installed.

63. **Interlocking Device.**—The small cylinder 25, Fig. 32, in the upper left-hand corner of the controller is the reversing cylinder, which controls the movements of the reverser, and thus determines the direction of movement of the car. The handle 2 of the reverse cylinder cannot be removed until it is moved to the off-position, and this motion of cylinder 25 operates an interlocking device that locks the main shaft 3 so that it cannot be moved. The removal of the small reverse handle, therefore, prevents the operation of the car from that controller, so that this small handle in effect constitutes a key to the operation of the train.

TYPE M CONTROL WIRING

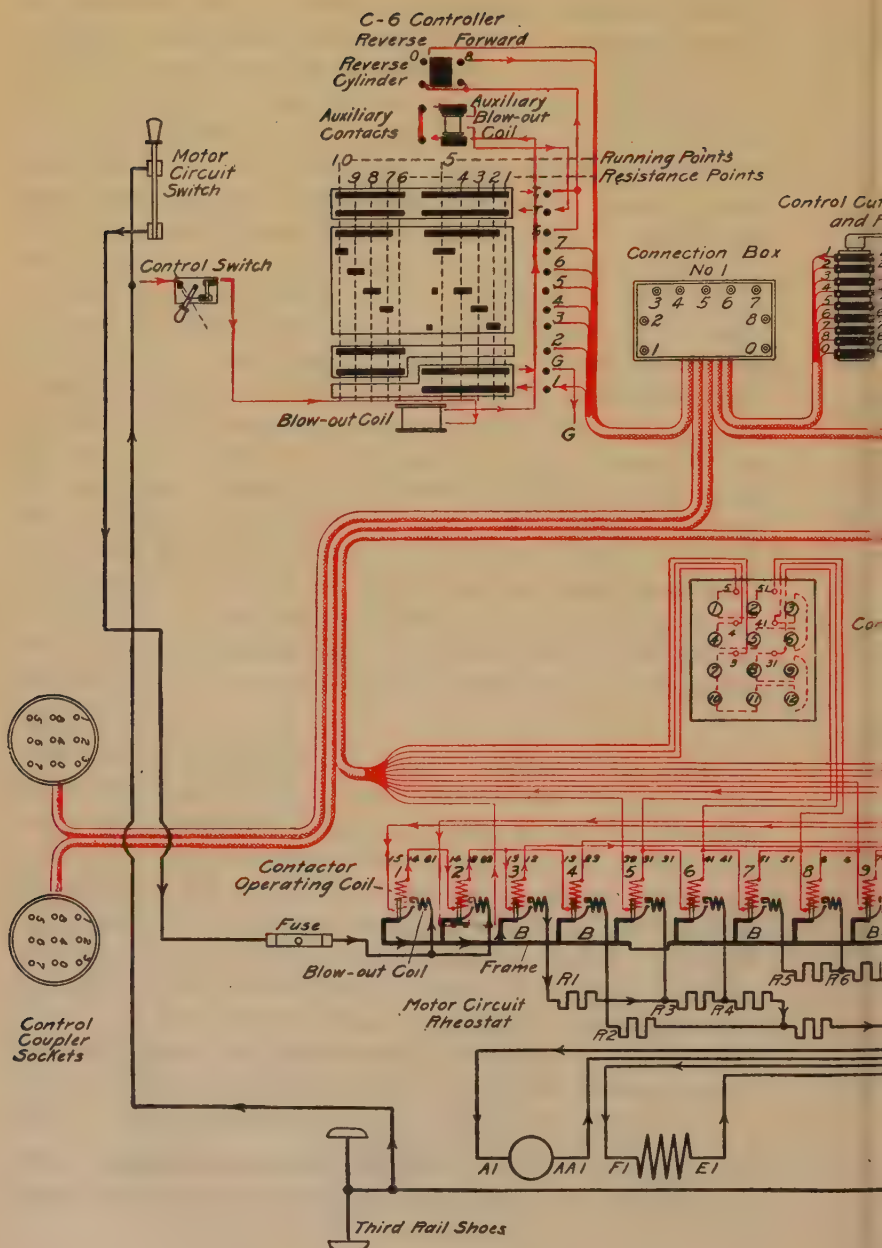
64. **Connections for Two C6 Master Controllers.**—In this system, for two motors, a diagram of which is shown in Fig. 33, type C6 master controllers govern the supply of current to the operating coils of the electromagnetic switches which constitute

the controller for the motors. The latter consists of thirteen switches or contactors, shown at bottom of the diagram, and a reversing switch, generally called a *reverser*. The control-circuit wires are shown in red and the motor-circuit wires in black, in order that each may be readily distinguished. The various operating devices are printed in black irrespective of whether they belong to the control circuit or to the motor circuit. As only relatively small currents are required to operate the switches, the wires passing from car to car are quite small.

At the upper left-hand corner of the diagram is shown one of the small reverse cylinders with the two control wires *0*, *8* connected to its contact fingers. Immediately below the reverse cylinder is the safety switch connected to the dead man's knob or handle. The auxiliary blow-out coil is connected between the two fixed contacts of the safety switch. Below this is the operating cylinder of the master controller, made up of four castings fixed on the same shaft. The black horizontal strips show the development of the contact segments, and all the segments on the same casting are, of course, connected electrically. At the bottom of the operating cylinder is the blow-out coil for suppressing the arcs at the contact fingers, the latter being represented by the vertical row of dots at the right.

65. Reverser Contacts.—The main contacts on the reverser, which is shown at the lower right-hand corner of Fig. 33, are shown by the heavy black bands engaged in pairs by the reverser main-circuit fingers marked *AA1*, *R7*, *A1*, *F1*, *A2*, *C*, *AA2*, *F2*. The operating coil to which wire *8* connects sets the reverser in the position in which the contacts are shown. Introduction of current to the operating coil connected to reverse wire *0* will cause the reverser contacts to shift bodily to the left. Fingers *a*, *b*, *c*, *a'*, *b'*, *c'* and narrow contacts *d*, *e*, *f*, *g*, *h*, *j* have to do with the control circuit, and the purpose of these contacts and fingers will be understood when the operation of the devices is considered. Small magnetic blow-out coils are shown at *k*, *k*.

66. Control Circuit, First Position.—It is assumed that the master-controller reverse cylinder in the wiring diagram, Fig. 33,



Sprague-General Electric M Control

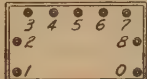
- Wire No 1 = Red
 " " 2 = Green & White
 " " 3 = Red & White
 " " 4 = Green
 " " 5 = Black & White
 " " 6 = Red & Green
 " " 7 = Yellow
 " " 8 = White
 " " 0 = Black

Switch

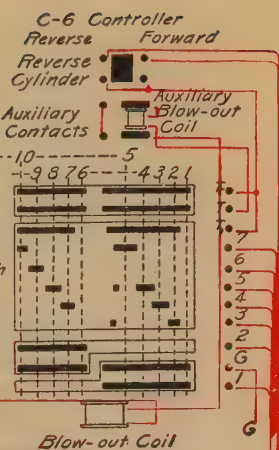


From this Cable
 No 8 Wire connects to 0
 No. 0 " " 8
 at Connection Board No. 2

Connection Box
 No. 2

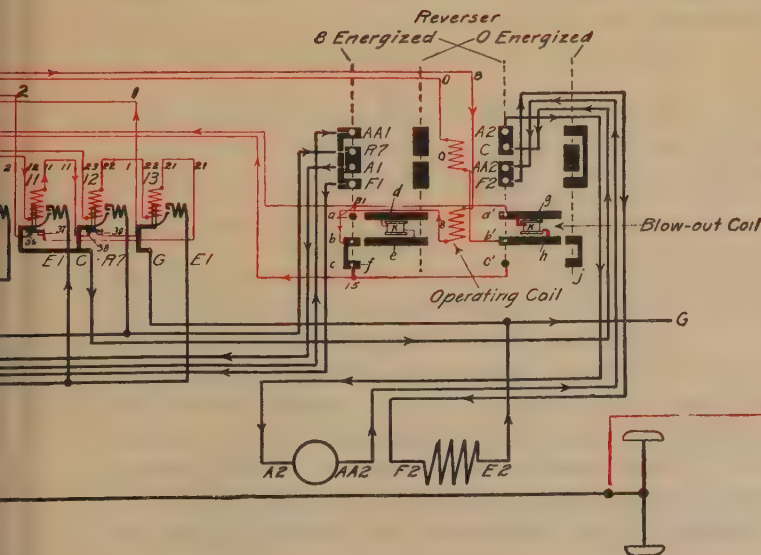


Control Switch



Running Points --- 10 --- 5
 Resistance Points --- 3 8 7 6 --- 4 3 2 1

Circuit Rheostat



is moved to the forward position and that the power handle is moved to the first point, so that the controller contact fingers occupy the position indicated by the vertical dotted line 1, on the development of the cylinder of the master controller. The coach or train is assumed to be operated from the left-hand controller. As soon as the operating handle is moved from the off-position, the safety switch closes, since the dead man's handle or knob is supposed to be pressed down. The arrow-heads show the paths of the control current and main-motor current when the master controller is on the first notch. The path of the control current is then as follows: Third-rail-control switch and fuse-main blow-out coil-auxiliary blow-out coil-auxiliary contacts-finger *T*-finger *T*₁-finger *8* by way of reverse cylinder-terminal *8* in connection box No. 1-terminal *8* on cut-out switch-reverser operating coil *8*-reverser control finger *b*-contact segment *f*-finger *c*-15-15-operating coil of contactor 1-14-14-operating coil of contactor 2-13-13-operating coil of contactor 3-12-12-operating coil of contactor 11-11-11-interlock contact 38-interlock contact 39-1-1-fuse 1 near control cut-out switch-cut-out switch 1-connection-box terminal 1-operating-cylinder finger 1-finger *G*-to earth at *G*. On the first point, therefore, contactors 1, 2, 3, and 11 are operated, and the reverser is at the forward position, shown in the illustration:

67. Motor Circuit, First Position.—The path of the motor current when contactors 1, 2, 3, and 11, in Fig. 33, are closed and the reverser is in the forward position is: Motor-circuit switch-main fuse- $\left\langle \begin{array}{c} \text{contactor } 1 \\ \text{contactor } 2 \end{array} \right\rangle$ -frame *B*-contactor 3-*R1-R3-R4-R7-R7* (on reverser)-*A1-A1-AA1-AA1* (on reverser)-*F1-F1-E1-E1* (on contactor 11)-*C-C* (on reverser)-*A2-A2-AA2-AA2* (on reverser)-*F2-F2-E2*-earth at *G*.

Contactors 1 and 2 are connected in parallel so as to reduce the current handled by each, because these contactors correspond to the trolley fingers of an ordinary controller, and the service imposed on them is more severe than on the others. Contactors 9 and 10, which come into use on the last series and last parallel notches, are connected in a similar manner.

68. Operation of Reverser.—In tracing the control circuit when the master controller is on the first point, it was assumed that the reverser already occupied the position shown in Fig. 33 and corresponding to that assumed when reverser operating coil 8 is energized. Suppose, however, that the reverser had, on account of previous use or for any other reason, occupied the opposite position, so that the small interlock fingers on the reverser rested on segments *d*, *e*, and *j* instead of *g*, *h*, and *f*. The current entering the reverser on wire 8 would then take the path through operating coil 8—finger *b*—segment *e*—blow-out coil *k*—segment *d*—contact finger *a*—81—81—interlock on contactor 2—82—82—fuse or control cut-out switch—earth at *G*. There can be no current in the motor circuit because contactors 1 and 2, called *line contactors*, are not closed. By the action of the current in coil 8, the reverser is thrown over to the requisite position. Then the operation proceeds as previously described. Blow-out coils *k*, *k* suppress all arcing that tends to follow the interruption of the control current.

69. Controller on Other Series Positions.—As the contact cylinder of the master controller is turned to positions 2, 3, and 4, Fig. 33, contactors 5, 6, and 7 are added to those already in operation, as can be seen by tracing out the control circuit. The result is to reduce the resistance in series with the motors. On the fifth position, which is the last series notch and one of the running notches, all the starting resistance is cut out. The path of the control current is as follows, starting from finger *T* on the master controller: *T*—*T*₁—*T*₀—finger 7—connection-box terminal 7—cut-out contact 7—coil of contactor 10—71—71—coil of contactor 9—6—6—coil of contactor 8—51—51—coil of contactor 7—41—41—coil of contactor 6—31—31—coil of contactor 5—32—32—fuse near control cut-out switch—earth at *G*. The path of the reverser control current remains as before, so that it is not necessary to trace it out.

Contactors 1, 2, 3, 5, 6, 7, 8, 9, 10, 11 are closed, thus short-circuiting all the resistance, so that the circuit through the two motors in series is: Motor-circuit switch—fuse— $\left\langle \begin{array}{c} \text{contactor 1} \\ \text{contactor 2} \end{array} \right\rangle$ —

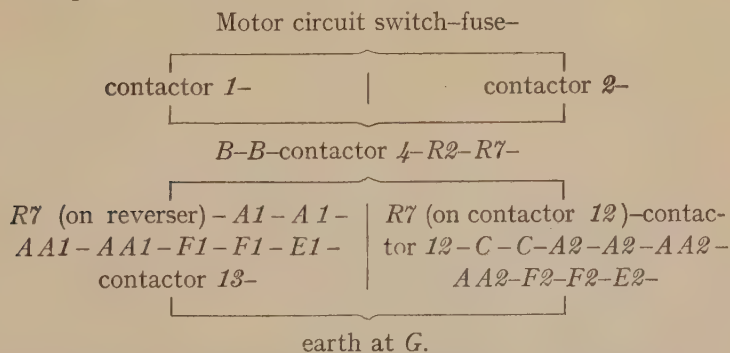
frame $BB - \begin{matrix} \text{contactor } 9 \\ \text{contactor } 10 \end{matrix} > - R7 - R7 - A1 - AA1, \text{ etc.} - \text{ground.}$

All the resistance is cut out and the two motors are in series.

70. Operation on Parallel Positions.—When the operating drum of the master controller is on position 6, Fig. 33, that is, the first parallel notch, the path of the operating current from finger T is as follows: $T - T_1$ —reverse cylinder—8—8 in connection box—8 on cut-out switch—coil 8 on reverser— $b - c - 15 - 15$ —coil of contactor 1—14—14—coil of contactor 2—13—13—coil of contactor 4—23—23—coil of contactor 12—22—22—coil of contactor 13—21—21—interlock 37—36—2—fuse 2—2 on cut-out—2 on connection box—finger 2 on controller—earth at G . This keeps the reverser in the position that it already had on the series notches, and operates contactors 1, 2, 4, 12, and 13.

In parallel circuits each path is indicated by the reference letters in the columns under the brackets. The joining of two or more columns by a bracket at the bottoms indicates that the circuits unite to form a single path.

The path of the motor current is then as follows:



The motors are therefore in parallel with two sections of the resistance in series with the circuit.

71. When the controller drum is placed in position so that contactors 5 and 6, Fig. 33, operate, they reduce the resistance in the circuit by placing a resistance section in parallel with one of the sections previously inserted. On the eighth position, contactor 7 is closed and resistance sections $R5 - R6 - R7$ are

placed in parallel with those already in use. On the ninth position, contactor 8 is closed and resistance section *R5-R6* is short-circuited. On the last parallel notch, contactors 9, 10 are closed, thus giving a direct connection between cable *B* and the wire *R7* running to the reverser.

On the parallel notches, the resistance in series with the motors is decreased by connecting sections in parallel rather than by cutting out existing sections. The advantage of this method is that, as the resistance is reduced, its current capacity is increased, and it is better able to carry the heavy current taken by the car on the parallel notches.

72. Summary of Operations.—As far as the final effect on the motors is concerned, the combinations effected by the movement of the master controller are practically the same as those effected by an ordinary series-parallel controller, though the master controller itself is not connected with the motors. In Table I is given a list of the contactors in operation for each position of the master controller.

TABLE I
ORDER IN WHICH CONTACTORS CLOSE

Number of Notch	Contactors in Operation												
I	I	2	3									II	
2	I	2	3	5								II	
3	I	2	3	5	6							II	
4	I	2	3	5	6	7						II	
5	I	2	3	5	6	7	8	9	10	II			
6	I	2		4								I2	I3
7	I	2		4	5	6						I2	I3
8	I	2		4	5	6	7					I2	I3
9	I	2		4	5	6	7	8				I2	I3
10	I	2		4	5	6	7	8	9	10		I2	I3

In Fig. 33, the connections have been explained by referring to the operation of devices on one car only. Where a number of cars are coupled together, the devices on all cars are operated synchronously by the currents in the train cables.

AUTOMATIC CONTROL

73. British Thomson-Houston Automatic Control.—In order to secure uniform acceleration of electric trains and prevent undue strain on the apparatus, some control systems are provided with **throttle relays** or **limit switches**, which are electromagnetic devices that open the control circuit when the main current reaches too great a value, and thus regulate the rate at which the contactors successively close. By the use of the throttle relay the handle of the master-controller can be moved at once to the full parallel notch, and the master-controller cylinder will follow step by step as it is allowed by this device.

Instead of the controller cylinder being positively driven by the spindle to which the operating handle is attached, it is connected to it by means of a spring, and a magnetically operated lock prevents the cylinder from following the movement of the operating handle so long as the current taken by the motors exceeds a predetermined amount. The device thus ensures the greatest possible acceleration without slipping of the wheels or injury to the apparatus. This type of control has been installed on the North Eastern Railway at Newcastle-upon-Tyne.

74. Automatic-Relay Control.—A system of multiple-unit control, similar to the type M, but having the throttle-relay feature, has been developed by the General Electric Company, and is known as the **automatic-relay control**. Each contactor is fitted with special auxiliary contacts in addition to those which carry the main current of the motors. These auxiliary contacts are utilized for the purpose of controlling the operating coil of one or more of the other contactors in such a way that the whole series of operations just described is carried on automatically, the switches closing in succession as the train accelerates, until the connections correspond to the position of the handle of the master controller. As in the case of the semi-automatic system on the North Eastern Railway, the rate at which the contactors are successively closed is independent of the rate at which the control handle is moved, but is determined by the limit or throttle switch.

75. Construction of Relays.—The main features of the throttle relay used with the Sprague-General Electric type M automatic-relay system are shown in Fig. 34. The relay consists of an iron core fixed to an iron framework, and a movable core, or plunger,

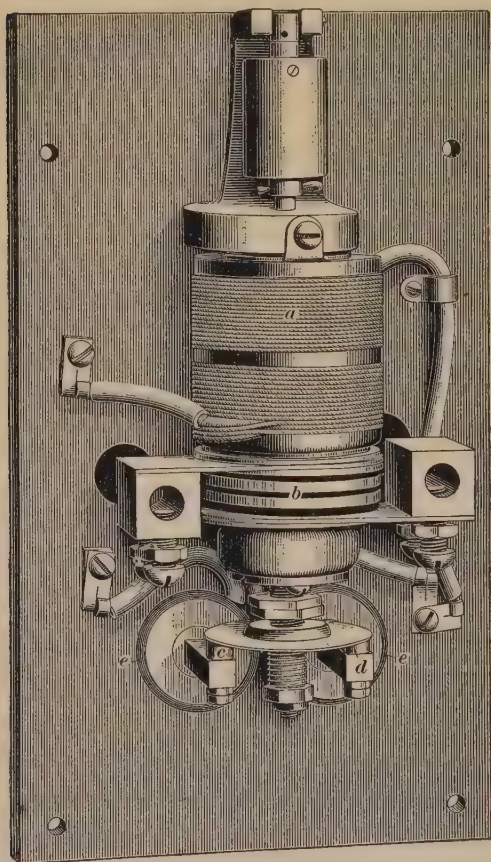


FIG. 34

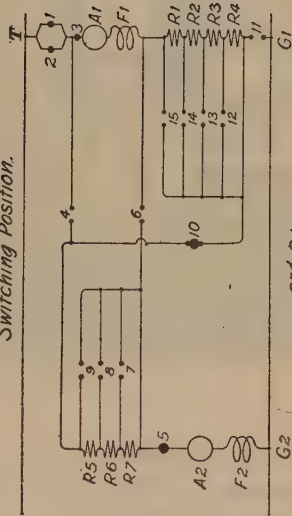
which helps to complete the magnetic circuit. Coil *b* is energized by the current supplied to one motor, and current from the control circuit passes through the coil *a* and through the contacts *c* and *d* by way of the disc. Blow-out coils *e* extinguish the arcs formed at *c* and *d* when the contact is broken. The top of the plunger is connected to a small piston, which works in a cylinder at the top of the relay; the cylinder is provided with adjustable throttle valves which control the rate at which the plunger rises.

76. Action of Relay.—If the current flowing in the main-circuit coil *b* is more than a predetermined amount, the plunger and its disc are lifted up, thus breaking the control circuit and preventing further progress of the control apparatus until the motor current has fallen sufficiently to allow the plunger and disc to drop.

Series.

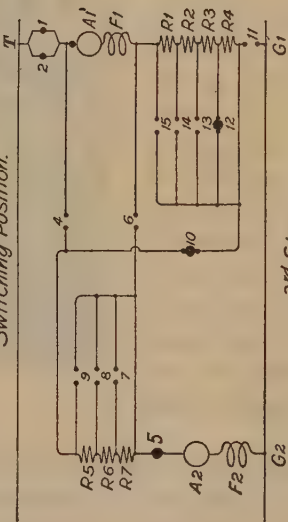
1st Step.

Switching Position.



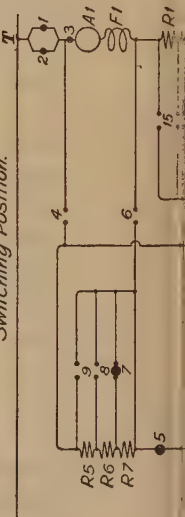
2nd Step.

Switching Position.



3rd Step.

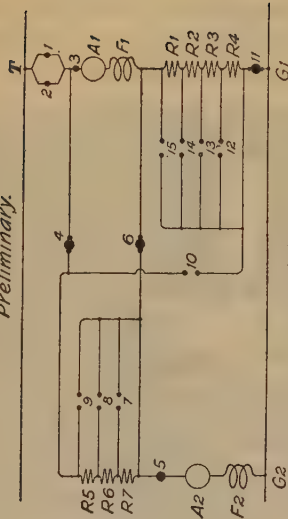
Switching Position.



Parallel.

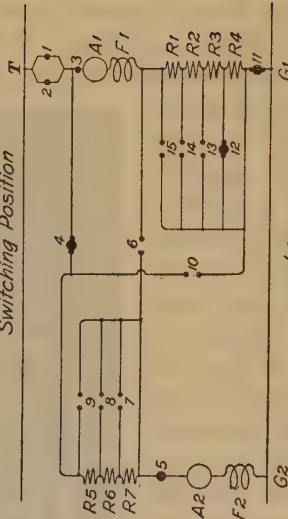
1st Step.

Preliminary.



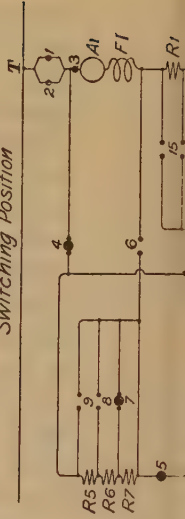
1st Step.

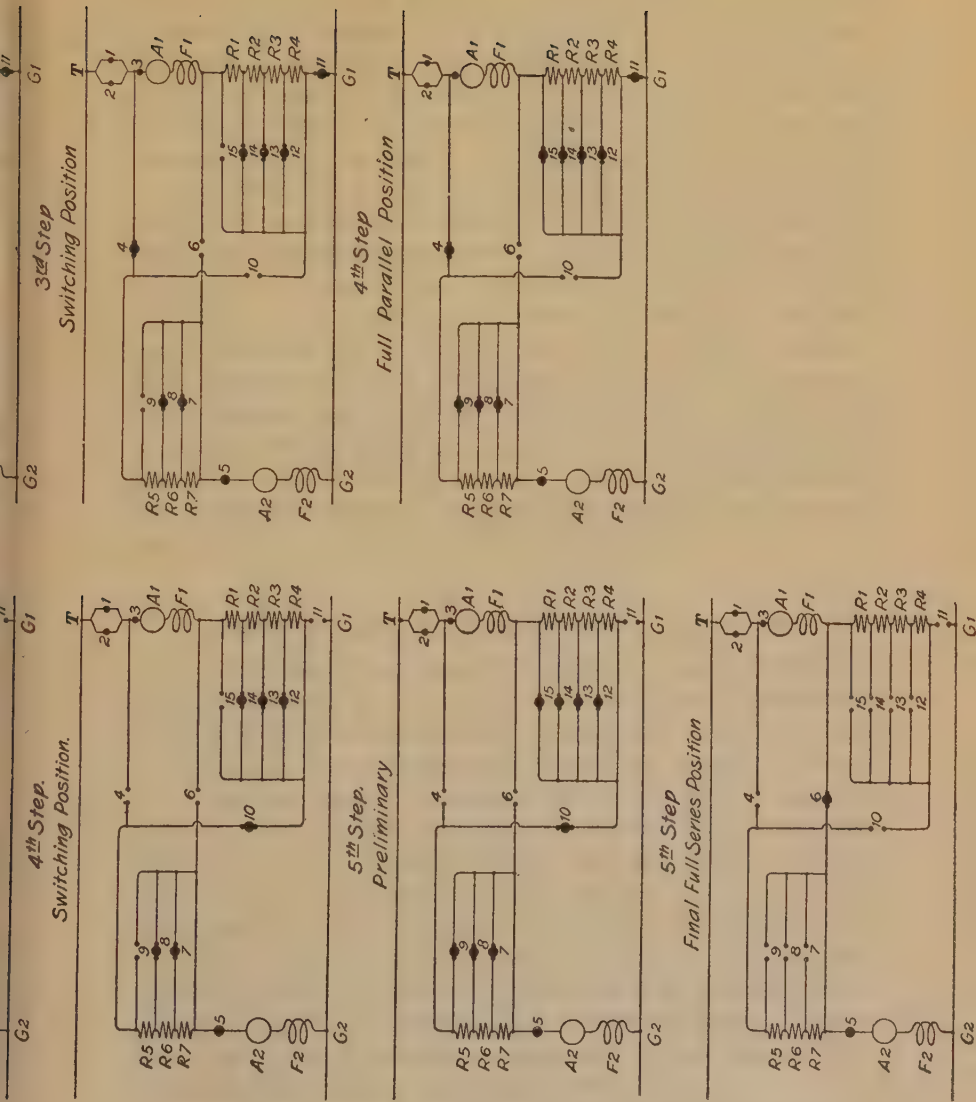
Switching Position.



2nd Step.

Switching Position.





With the plunger at lowest position there is a large air gap included in the magnetic circuit, and greater magnetizing force is needed to produce a given pull than when the plunger is in the top position. In order to adjust the pulls so that they are properly effective in both positions of the plunger, two coils are used, as shown in Fig. 34. When the plunger is in the lowest position both coils *a* and *b* are energized, but when the plunger has risen a small amount, coil *a* is cut out of circuit by the disc being pulled away from the contacts *c* and *d*. The plunger then completes its motion due to current in coil *b* only. The disc and the contacts *c* and *d* are of iron, and this local magnetic circuit is magnetized by the blow-out coils *e, e*. Now, when the plunger begins to rise, it compresses a spring, the top of which presses against the under side of the disc. When this pressure is equal to the magnetic pull between the contacts *c, d* and the disc, the latter is released and so breaks the circuit of coil *a*. To prevent the disc and contacts from sticking, their surfaces are coated with a layer of non-magnetic metal.

BRIDGE SYSTEM OF SERIES-PARALLEL CONTROL

77. Transition From Series to Parallel.—A method of transition from series to parallel connection of the motors in multiple-unit and other systems of control, by which the motors are neither open-circuited nor short-circuited during the change, is known as the **bridge system**. Diagrams of the connections for each position of the controller handle are given in Fig. 35, the *open contactors* being represented by two dots separated by a short space, and the *closed contactors* by single dots.

The method of operation is as follows: When the master controller is moved to its first step or the first series-switching position, the operating coils of contactors *1, 2, 3, 5*, and *10* are energized and the corresponding contactors close. This is shown by the black dots on the diagram of circuits for first-step series-switching position at the top of Fig. 35.

Current flows from *T* on the positive main through contactors *1* and *2-3*—armature *A1*—field *F1*—resistances *R1-R2-R3-R4*—switch *10*—resistances *R5-R6-R7*—switch *5*—armature *A2*—field

F2—to earth at G_2 . The motors are therefore in series with all the resistances. On the next position, second step, the resistance contactor *12* is closed, and on succeeding steps up to the full series position contactors *7* and *13*, *8* and *14*, and then *9* and *15* are closed in the order of enumeration at a rate determined by the limit switch, thus gradually cutting out the resistance. In the final full series position contactor *6* closes, and the opening of interlocks on this contactor breaks the circuit of the operating coils of contactor *10* and of the resistance contactors *7*, *8*, *9*, *12*, *13*, *14*, *15*. The path of the current is now from *T* on positive main—contactors *1* and *2-3-A1-F1*—contactors *6-5-A2-F2*—earth at G_2 . The motors are thus connected in series without any resistance in series with them.

78. On the first-step parallel or preliminary switching position, see Fig. 35, current is supplied to the operating coils of contactors *4* and *11*, the closing of which opens the circuit of the operating coil of contactor *6*. It will be seen that the effect of the first of these operations is to connect the resistances in series across the mains from *T* through contactors *1* and *2-4-6-11* to earth at G_1 and G_2 . If the resistances are suitably designed, the current taken by them will be equal to that taken by the motors in full series, and in that case the current in each motor will be unchanged by the closing of contactors *4* and *11*, but the current through contactor *6* will be reduced to nothing. Under these conditions, the motors are in parallel, one being in series with resistances *R1-R2-R3-R4* and the other with resistances *R5-R6-R7*, and contactor *6* opens sparklessly. On the succeeding positions of the master controller, as shown in the various diagrams, Fig. 35, resistance is cut out as before by the successive closing of the resistance contactors until the motors are in full parallel. During the transition the current in each motor is not appreciably altered, and thus there is no sudden variation of tractive force, and therefore no jerk during the acceleration period. A further advantage is that no arcs are formed at the contact surfaces of the contactors because the circuit is not broken, except when the motors are switched out of circuit in order to stop the car.

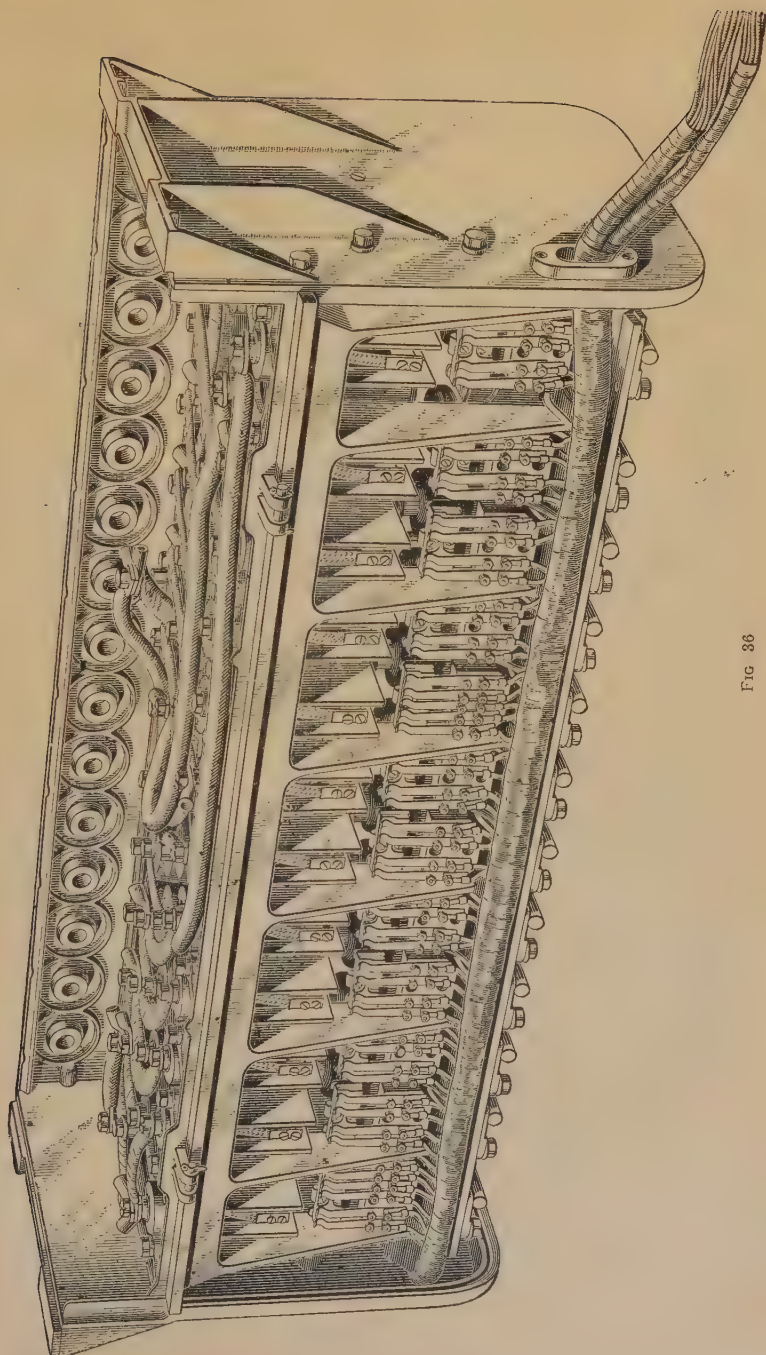


FIG 36

WESTINGHOUSE ELECTRO-PNEUMATIC CONTROL

CONTACTORS AND CONTROLLER

79. Principle of Action.—In the Westinghouse unit-switch system compressed air is used to operate the contactors by means

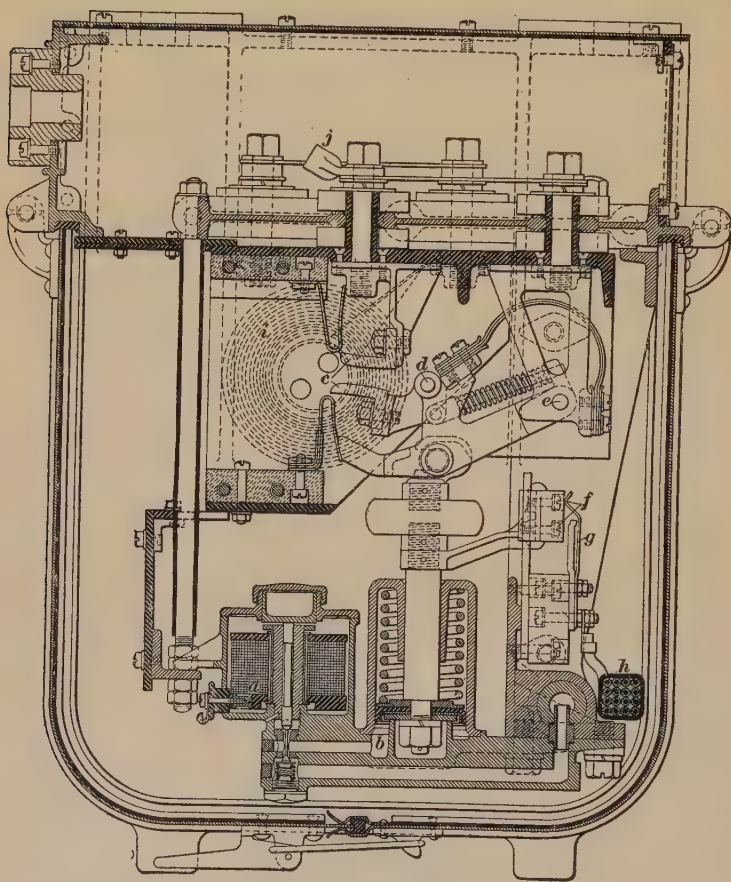


FIG. 37

of small valves worked by electromagnets. A storage battery is installed on the train for the purpose of supplying current to

these electromagnets, the supply being regulated by the driver through the agency of the master controller. The battery consists of fourteen cells arranged in two sets of seven cells each, the connections being such that, while one set is being used, the other is being charged. It is thus unnecessary to connect several magnets in series, as in the Sprague system, in which current for energizing the contactor magnets is taken direct from the line. The control in the unit-switch system is automatic, the rate of switching on being governed by a limit, or throttle, switch. Most of the contactors are provided with double-wound electromagnets, the two windings being insulated from each other. One winding serves to close the contactor and the other to hold it closed.

80. Electro-Pneumatic Contactor.—A Westinghouse unit-switch group in which a number of contactors are arranged in line on a frame is shown in Fig. 36, and a sectional view of a single unit switch is shown in Fig. 37. When the operating magnet *a*, Fig. 37, is energized, it opens a valve and allows air, under a pressure of about 70 pounds per square inch, to enter the lower portion of the air cylinder *b*, thus forcing the piston upwards and closing the main contacts *c*. The support of the movable switch contact is pivoted to the switch arm at *d*, and the arm is pivoted at *e* to the frame, thus, when the switch closes, giving a rubbing action, which is an aid in securing good contact. On opening the circuit of the operating valve, the air valve closes,

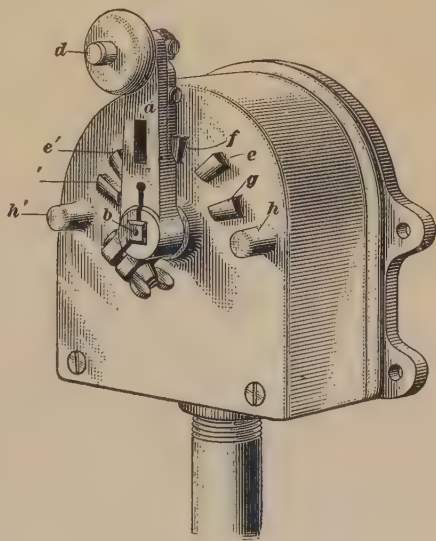


FIG. 38

the air cylinder *b* exhausts to the atmosphere, and the piston is forced downwards by a spring, thus separating the contacts *c*.

81. Interlocks and Blow-Out Coils.—On the piston rod which operates the main contactor is an arm carrying a block on which are mounted the interlock segments, one of which is shown at *f*, Fig. 37. The interlock segments make or break contact with fingers, one of which is shown at *g*, and which are connected to wires in the control cable *h*. To suppress the arc formed on breaking the main circuit at the contact *c*, a blow-out coil *i* is provided. As in the contactor previously described, current passes from the lower contact to a terminal on the frame through a flexible connector, while the insulated terminal *j* is in connection with the upper contact. It is worthy of note that the normal position of the switch is open, so that a failure of air supply or interruption of the control circuit opens all the switches. Similar switches have been combined together in a different way, namely, by arranging them radially round a common blow-

out coil. This arrangement, known as the *turret controller*, was installed on the Metropolitan Railway but found to be unsuitable, and so was replaced by the arrangement shown in Fig. 36.

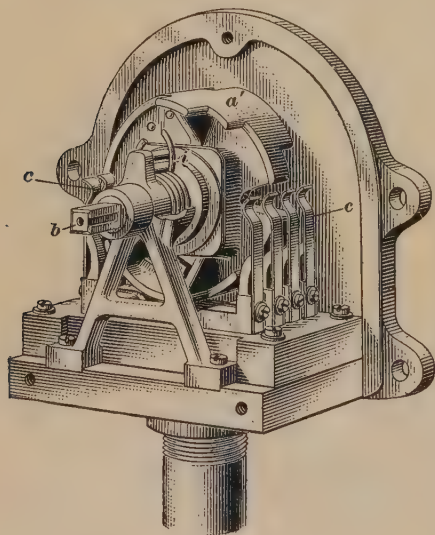


FIG. 39

Fig. 39. The cylinder *a'* consists of a single metal spider mounted on a horizontal shaft *b*, the turning of which causes

82. Master Controller.

One form of master controller used with the Westinghouse unit switch is shown complete in Fig. 38, and with the cover removed in Fig. 39. The operating handle *a*, Fig. 38, is shown in the off-position of cylinder *a'*,

the cylinder to engage fingers *c*, *c*. The operating handle *a*, Fig. 38, can be placed in position only when the controller cylinder is at the off-position, and to rotate the handle, pin *d* must be depressed, thus raising a small lever *f* that interferes with lugs *e*, *g*, *h* or *e'*, *g'*, *h'* cast on the cover. A movement of the operating handle to the right corresponds to a forward motion of the car or train, and a movement to the left reverses the motion. If the operating handle is moved to the position marked by lug *g*, the circuit combinations will automatically change until the motors are in full series across the line. As long as the operating handle is kept in this position, the combinations will not change, but an advance to the position marked by lug *h* will automatically change the combination until the motors are in parallel across the line. If the handle is released at any stage of its operation, spring *i*, Fig. 39, will return it to off-position, in which all circuits are automatically interrupted.

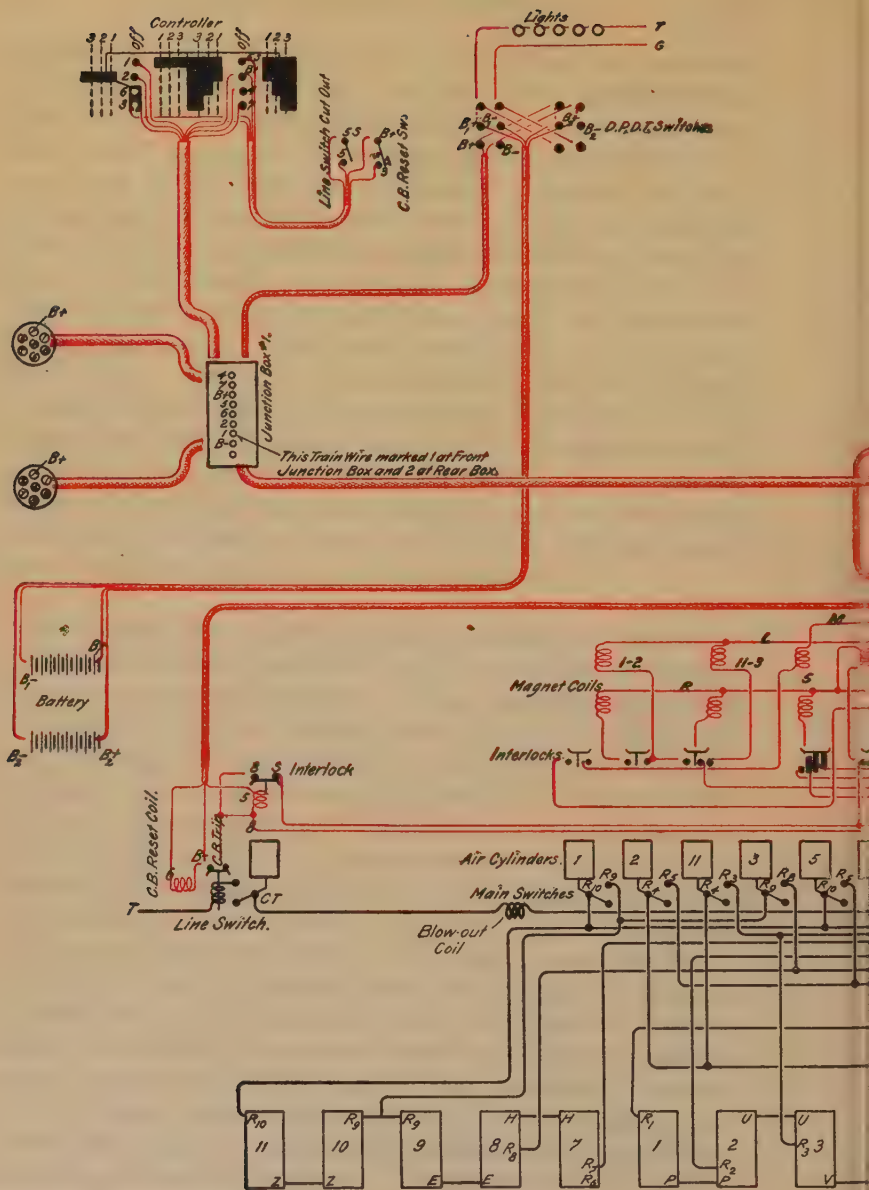
UNIT-SWITCH CONTROL WIRING

83. Wiring Diagram.—The diagram of connections for two Westinghouse master controllers used in connection with a unit-switch group to control two motors is shown in Fig. 40. The master-controller cylinders are indicated near the upper corners of the diagram, the three positions of the contact fingers being indicated by the dotted lines numbered 1, 2, 3. The control circuits are indicated in red and the motor circuits in black, but contacts on all apparatus, whether for the control or the power circuits, are indicated in black. Contactors or unit switches 1 and 2, 11 and 3, 9 and 10, 4, 12, and 13 always close or open in groups, so a single operating coil is provided for each group. In the description of the action of the control system, the controller at the left of the diagram is assumed to be in use. The interlocks for any unit switch are placed vertically over the switch.

84. Interlock Connections.—Some of the contactors in the Westinghouse unit-switch systems are provided with auxiliary contacts or interlocks, consisting of fixed contacts indicated in Fig. 40 by black dots or vertical strips, and movable contacts

indicated by horizontal black lines. The latter are connected with the main switches in such a way that, when the main switch closes, the movable contact or interlock arm moves downwards. In switches 7 and 12 the interlock closes when the main contact opens, but in the remaining contactors, excepting 13, both interlock and main switch open and close together. Contactor 13 is provided with a double set of contacts so as to close one circuit when open and another when closed. Contactors 4 and 5 are special in construction. In each of them, when the main switch is open, the interlock arm makes contact with the two right-hand strips; soon after it has started its downward stroke it makes contact with the third strip, and just before the end of the down stroke it makes contact with the left-hand strip and disengages with the right-hand strip. The interlocks prevent the unit switches from closing in any but the proper order, and in conjunction with a line switch or overload circuit-breaker make the system of control automatic.

85. Control Circuit, First Forward Position.—Movement of the master-controller handle, Fig. 40, to its first forward position establishes connections as follows: Master-controller finger *B+*, connected to the positive battery terminal, connects to fingers 5*S* and 1 through the master-controller cylinder. Assuming the line-switch cut-out to be closed, the path is: Finger 5*S*–5*S* on line-switch cut-out–terminal 5, junction box 1–5, box 2–coil 5 on line switch–line switch or circuit-breaker contacts, called in diagram *C.B.* trip–negative battery wire *B*–. Excitation of coil 5 closes the line switch *CT* by admitting air to its operating cylinder. The closing of the line switch provides a trolley connection at *T*, and allows current to flow from a point near contactor 12 through the resistance *C* and lifting coil of the line relay to earth *G*, thereby closing the line relay, the contacts 8 and *S* of which are in parallel with the line-switch interlock 8, *S*. The line-switch interlock is always open when the switch is closed. Simultaneously, a current from finger 1 passes through reverser coil 1 and thence to the negative side of the battery. This current opens the valve controlled by reverser coil 1, and if the reverser is not already in the forward position, it will promptly move to this position.



Car Wiring for Troughhouse Unit Switch Control

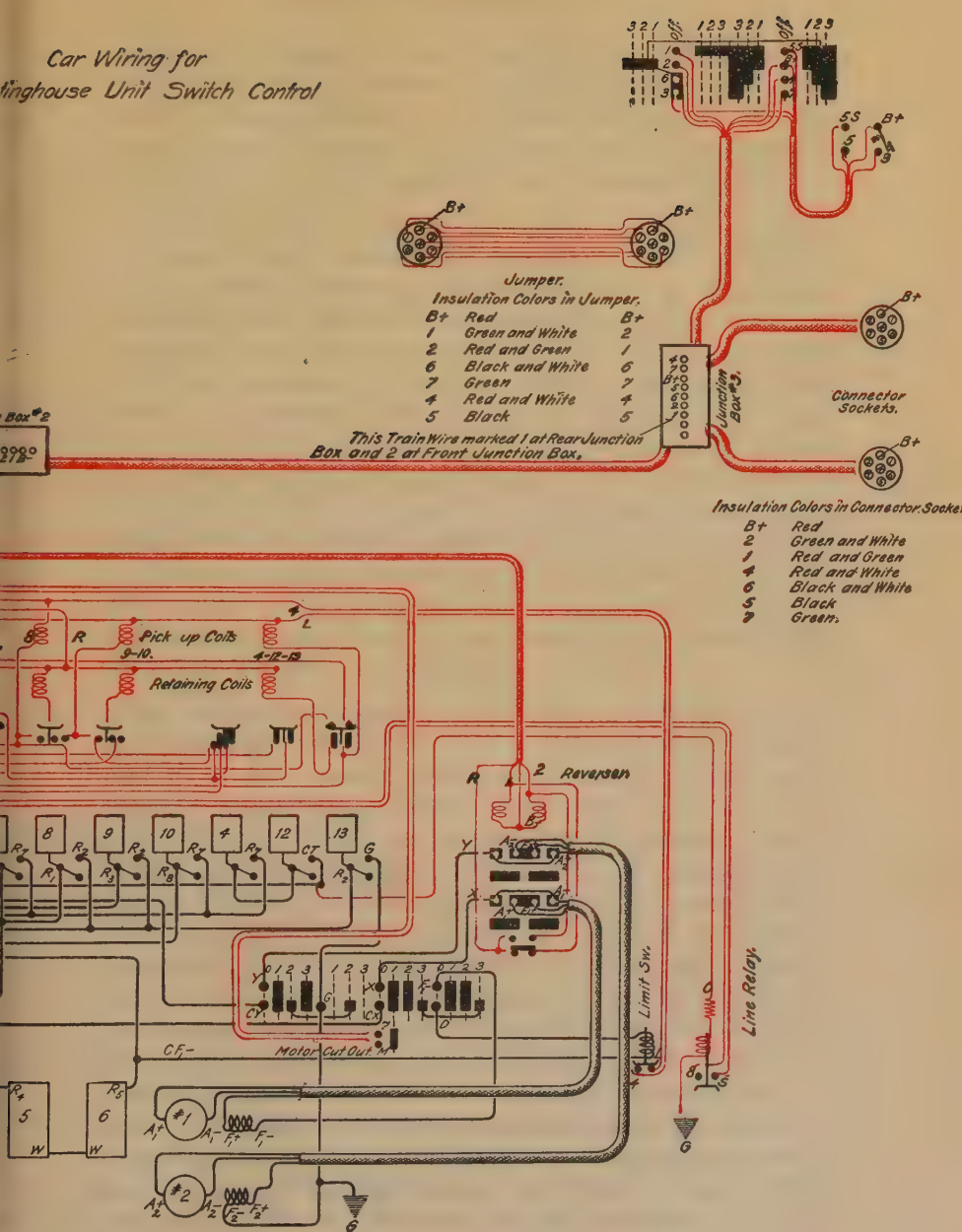


FIG. 40

As soon as the reverser has moved the full length of its travel, the safety switch shewn just below it establishes connection between wire *I*, which is connected to the positive battery wire *B+*, and wire *R*, which represents the positive sides of the retaining coils *1-2*, *11-3*, *5*, *8*, *9-10*, *4-12-13*, and the pick-up coils *6* and *7*.

86. The reverser must be fully thrown forwards or back, otherwise its safety switch will not connect wire *R*, Fig. 40, to the battery. Assuming the reverser to be at the extreme end of its travel, wire *R* will become *B+*, and current flows from *R*-pick-up coil *6*-*S*-line-relay contacts *S-8-8* on line switch -*C.B.* trip contacts-*B-*, thereby operating unit switch *6* and closing its interlock. The closing of this interlock causes current to take path *R*-pick-up coil *7*-upper interlock contacts of unit switch *13*-right-hand contacts of interlock of switch *5* and of interlock of switch *4*-contacts of interlock of switch *6*, here joining with the current from pick-up coil *6* and flowing with it through the line-relay contacts to *B-*, and thereby operating unit switch *7*. The motors are now in series with resistance, as will be seen by tracing out the main-current path, assuming the line switch and unit switches *6* and *7* to be closed.

87. **Full Series Position.**—On moving the master controller to the second position, thereby connecting controller finger *4*, Fig. 40, to *B+*, current flows out on wire *4*-pick-up coil of switch *8*, which closes switch *8*-interlocks of switches *5*, *4*, and *6*-*S* and with the operating currents of switches *6* and *7*, through the line-relay switch to *B-*. A branch of wire *4* connects through the limit switch to wire *L*, which is the positive side of the pick-up coils of unit switches *9-10*, *11-3*, *1-2*, and *4-12-13*. The closing of the interlock of switch *8*, due to the operation of unit switch *8*, has given a *B-* connection to retaining coil *8* and also to the pick-up coil *9-10*, which closes switches *9* and *10*. The closing of switch *9* gives its retaining coil a *B-* connection through its own interlock and interlocks of switches *8*, *5*, *4*, and *6*. The operation of unit switch *9* also gives a *B-* connection to pick-up coil *11-3*, which immediately causes unit switches *11* and *3* to close. These switches are held closed by their retaining coil, which gets its *B-* connection through interlocks *11*, *9*, *8*, *5*, *4*,

and 6. The closing of unit switch 11 closes its interlock, through which a *B—* connection is given to pick-up coil 1-2, which causes switches 1 and 2 to close. These switches are then held closed by their retaining coil getting a *B—* connection through interlocks of switches 2, 11, 9, 8, 5, 4, and 6. The motors are now in full series across the line, all the resistance being cut out by the closing of switches 8, 9-10, 11-3, 1-2.

88. Full Parallel Position.—On moving the master controller to the third position, finger *B+*, Fig. 40, is connected to wire 7 and battery current takes the path : 7-motor cut-out interlock-wire *M*-pick-up coil 5-interlocks of switches 1, 13, 5, 4, 6-*S—B—*, by way of the line relay, as in preceding cases. The closing of switch 5 first completes the circuit of its own retaining coil through the middle contacts on interlock 5-interlock 4-interlock 6-*B—*, as usual. Toward the end of the piston stroke, the sliding contact on interlock 5 breaks connection with the right-hand contact, thereby depriving the pick-up and retaining coils 7, 8, 9-10, 11-3, and 1-2 of their negative or *B—* connections and causing these switches to open. When switch 5 is fully closed, the short contact of its interlock completes the circuit through the pick-up coil 4-12-13 as follows : *B+* 4-*L*-pick-up coil 4-12-13-interlock on switch 7-interlock on switch 12-interlock on 5-interlock on 4-interlock on 6-line relay-*B—*. Switches 4, 12, and 13 do not close until switch 7 has fully opened, because interlock 7 is part of the circuit through pick-up coil 4-12-13, and this interlock is closed only when its unit switch is entirely open. When switch 13 closes, a negative or *B—* connection to the retaining coil is established through the lower interlocks of switch 13 and the interlocks of switches 7-12-5-4 and 6. In the first part of the downward movement of the piston of switch 4, its interlock engages the low contact, thereby establishing another *B—* path through the middle fingers of the interlock of switch 4. The first path is broken in two places by operation of unit switches 4 and 12 when these switches are nearly closed, and the *B—* connection of the retaining coil of switch 5 is also broken. Unit switch 5 is in use only during the transition from series to parallel connection of the motors.

89. The effect of the various combinations formed in the control circuit is to connect the motors in parallel, but having five sections of resistance in series with each. The contactors in the unit-switch group, Fig. 40, which are closed are 6, 4-12-13. The full closing of switch 4 connects the short contact of its interlock to *B*—, thereby providing a *B*— connection for the pick-up coil of the 9-10 magnet, which causes switches 9 and 10 to close. The closing of switch 9 causes the consecutive closing of 11-3 and 1-2, thus connecting the motors in full parallel.

DICK-KERR CONTROL SYSTEMS

MULTIPLE-UNIT CONTROL

90. **Dick-Kerr Contactor.**—A view of the Dick-Kerr contactor is shown in Fig. 41. The contactors are arranged in groups of four, each group being placed in an iron box. In the illustration, *a* is the iron supporting frame, *b* the operating coils, *c*, *c'* are the switch contacts, and *d* the insulating supports for the switch parts. The lower end of the plunger may be seen at *e*, and the upper end, which is not shown, carries the contact *c'*. The contact *c* is hinged and kept down by a spring, so that when *c'* is pressed upwards by

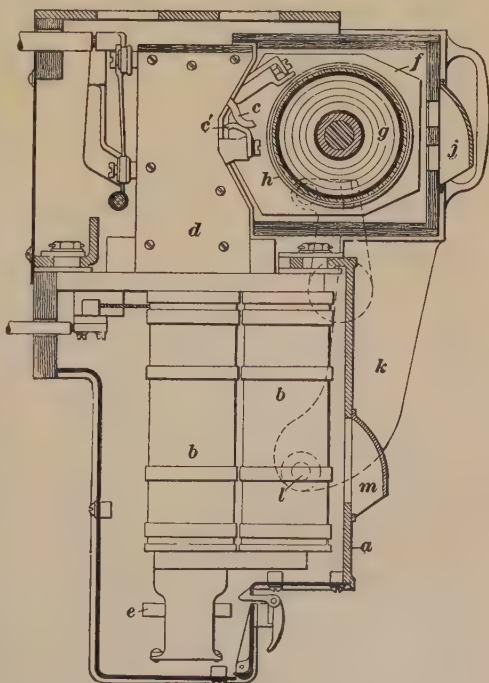


FIG. 41

the pull on the plunger a slight rubbing action takes place between the contacts, and this helps to keep them clean and to give good contact. Ventilation is provided for by the two openings j and m , air being drawn in at the lower opening and expelled at the upper one.

When current is cut off from the operating coils, the contact between c and c' is broken simply by the action of gravity. As the operating coil carries the current of one motor and thus requires few turns, its inductance is low, and therefore the contactor is very prompt in action. The inductances of two coils, one wound with fine wire of many turns and the other with thick wire of few turns, are quite different even when the effective magnetic pulls given by the two coils are the same. The reason for this is because the inductance varies as the square of the number of turns. It is possible, therefore, by using a heavy controlling current for the contactors, to secure prompt action.

91. Metallic-Shield Blow-Out.—The contactors in one group are separated by partitions f , Fig. 41, which effectually prevent the arc from passing from one pair of contacts to those adjacent. The blow-out coils g for each group are mounted on a common iron rod and supported by the carrier k . The rod on which the coils are mounted is not large enough to materially affect the magnetic field, so that the field effective for blowing out arcs may be taken as proportional to the current flowing. The blow-out coils are provided with non-magnetic metal casings, or shields, h , which come very near to the tips of the contacts. When the circuit is broken by the opening of the contacts c, c' , the arc passes to the shield h and is forced outwards by the magnetic field toward the opening j and broken. The final break of the arc occurs at some point on the shield h , and tests have shown that the shield is uninjured and the main contacts are entirely relieved of the arc. Because of the action of the magnetic field in breaking the arc on the shield h , the arrangement just described is known as the **metallic-shield blow-out**.

92. Dick-Kerr Master Controller.—The master controller used with the Dick-Kerr multiple-unit system is provided with three

distinct contact cylinders, or barrels, *A*, *B*, and *C*, as shown in Fig. 42. The barrel *A*, called the **switching barrel**, is connected directly to the operating handle. On this barrel are mounted the contacts which close the by-pass circuits through the operating coils of the reversers and contactors. The barrel which operates the contactors is called the **contactor barrel**; it is mounted immediately below the switching barrel, and is operated by means of a lug *a*, which is moved by a cam *b* at the bottom of the switching barrel *A*. The cam *b* is shaped so as to allow the switching barrel to move through a certain angle before the contactor barrel is moved. The object of providing this free movement of the switching barrel is to allow the control coils to become demagnetized and the contactors to open by the time the operating handle reaches the off point. The operating handle is fitted with a mechanical lock which permits the barrels *A* and *B* to be moved one step at a time. Before the handle can be advanced from one notch to the next, a slight backward movement is necessary. The **reversing barrel** is indicated at *C*, and is provided with a small reversing handle *c* so that it can be turned to make the proper connections to the operating coils of the reversers. In every case the main circuits are broken at the contactors and not at the controller fingers, so blow-out coils are not necessary.

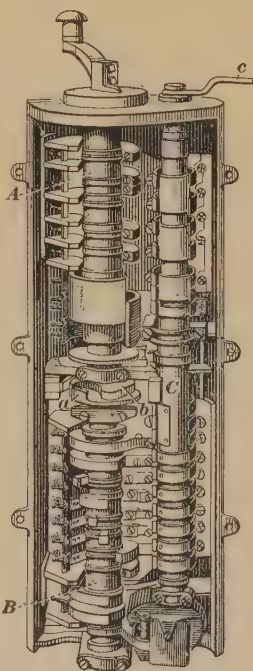


FIG. 42

93. Principle of Operation.—In the Dick-Kerr multiple-unit system supplied to the Lancashire & Yorkshire Railway, all the contactors except those for the reversers are operated by the current flowing to one of the driving motors, and not by a separate control circuit as in the systems previously considered.

To start the motors, the controller handle is turned so that the by-pass switches *a*, Fig. 43, are closed, and the two-way switch *b* disconnected from the earth at G_1 and turned to the lower contact. Current flows from the collector shoe *c* through the motors d_1 and d_2 and solenoids *e* to earth at G_2 . Directly the solenoids are excited, they close the contacts *f*, so that it is unnecessary to keep the by-pass switches *a* closed, and they can be opened sparklessly. By joining other solenoids in parallel with *e*, *e*, as indicated by the dotted lines, and governing the flow of current by a suitable controller, other contactors or switches can be arranged to cut out sections of resistance and to connect the motors in parallel.

94. Wiring Diagram.—A diagram of the connections of the Dick-Kerr multiple-unit controller to the car wiring is shown

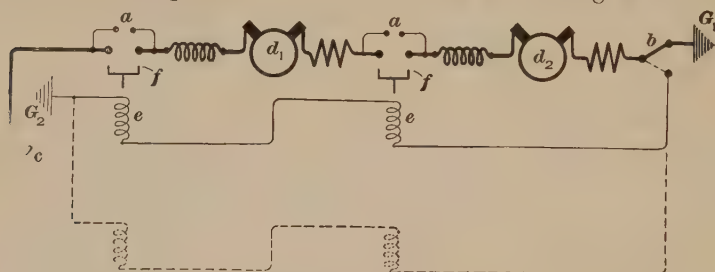


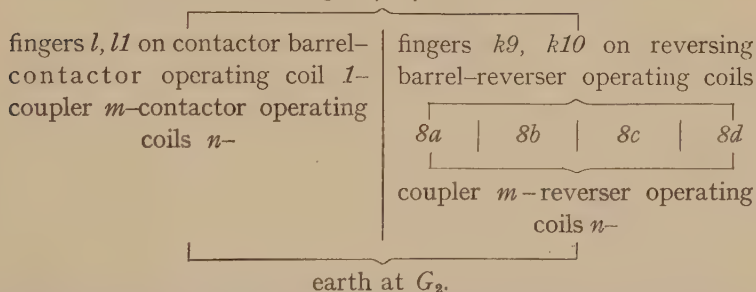
FIG. 43

in Fig. 44. In order to simplify the connections, the operating coils of the contactors and reversers are shown at one side, though their true positions under their contactors are indicated by numbers and letters corresponding to the coils. The contactors are lettered and numbered the same as the coils.

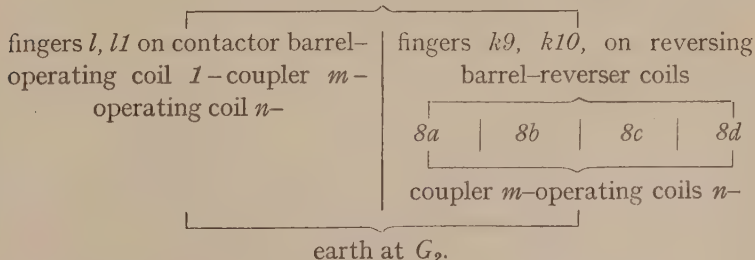
The switching barrel *A* of the controller can move through an angle corresponding to the distance *ab* before the contactor barrel *B* begins to move. At the base of the controller there is a small magnet coil *d* which, when excited, locks the contactor barrel. The reversing barrel is shown at *C*, the positions of the fingers for forward and backward running being marked.

95. Circuits on Series Positions.—In order to start the motors, the reversing barrel *C*, Fig. 44, is turned to the forward position, so that the two rows of contact fingers, which are shown as

black dots, occupy the positions indicated by the lines *e* and *f*, or to the backward position, so that the fingers are at the positions indicated by the lines *e* and *g*, and the operating handle is turned until both switch and contactor barrels are in position 1. If the reverser fingers are in the forward positions *e* and *f*, current flows as follows: Collector shoe *h*—circuit-breaker *i*—fingers *j1*, *j* on switch barrel *A*—fingers *k*, *k1* on reversing barrel *C*—armature *A1*—fingers *k2*, *k3* on reversing barrel—field *F1*—resistances *R1*, *R2*—fingers *l8*, *l9* of contactor barrel—magnetic lock coil *d*—fingers *j3*, *j4* on switch barrel—fingers *k4*, *k6*, on reversing barrel—armature *A2*—fingers *k5*, *k7*, on reversing barrel—field *F2*—resistances *R3*, *R4*—fingers *j6*, *j7* on switch barrel—



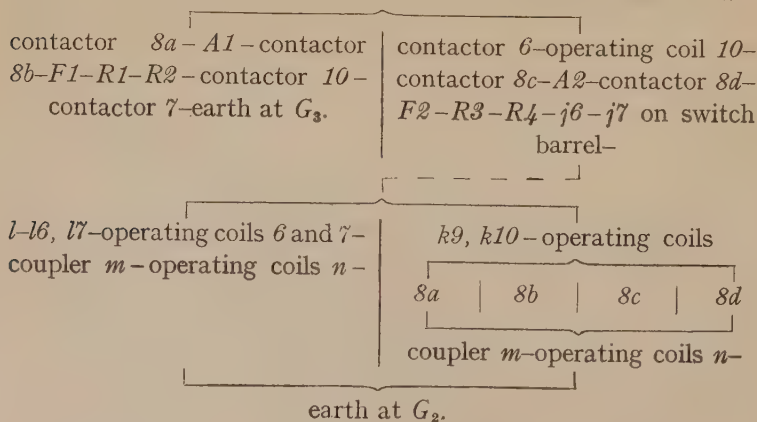
The couplers *m* are between the motor coaches and the operating coils or control magnets *n* are on the other motor coach. Contactor 1, Fig. 44, is closed by the action of operating coil 1; this short-circuits the locking magnet *d* and permits the contactor barrel to be moved forwards. Contactors 8*a*, 8*b*, 8*c*, and 8*d* on the reversers are also closed, and current flows in the following circuit: Collector *h*—*i*—contactor 8*a*—armature *A1*—contactor 8*b*—field *F1*—*R1*—*R2*—contactor 1—contactor 8*c*—armature *A2*—contactor 8*d*—field *F2*—*R3*—*R4*—fingers *j6*, *j7* on switch barrel—

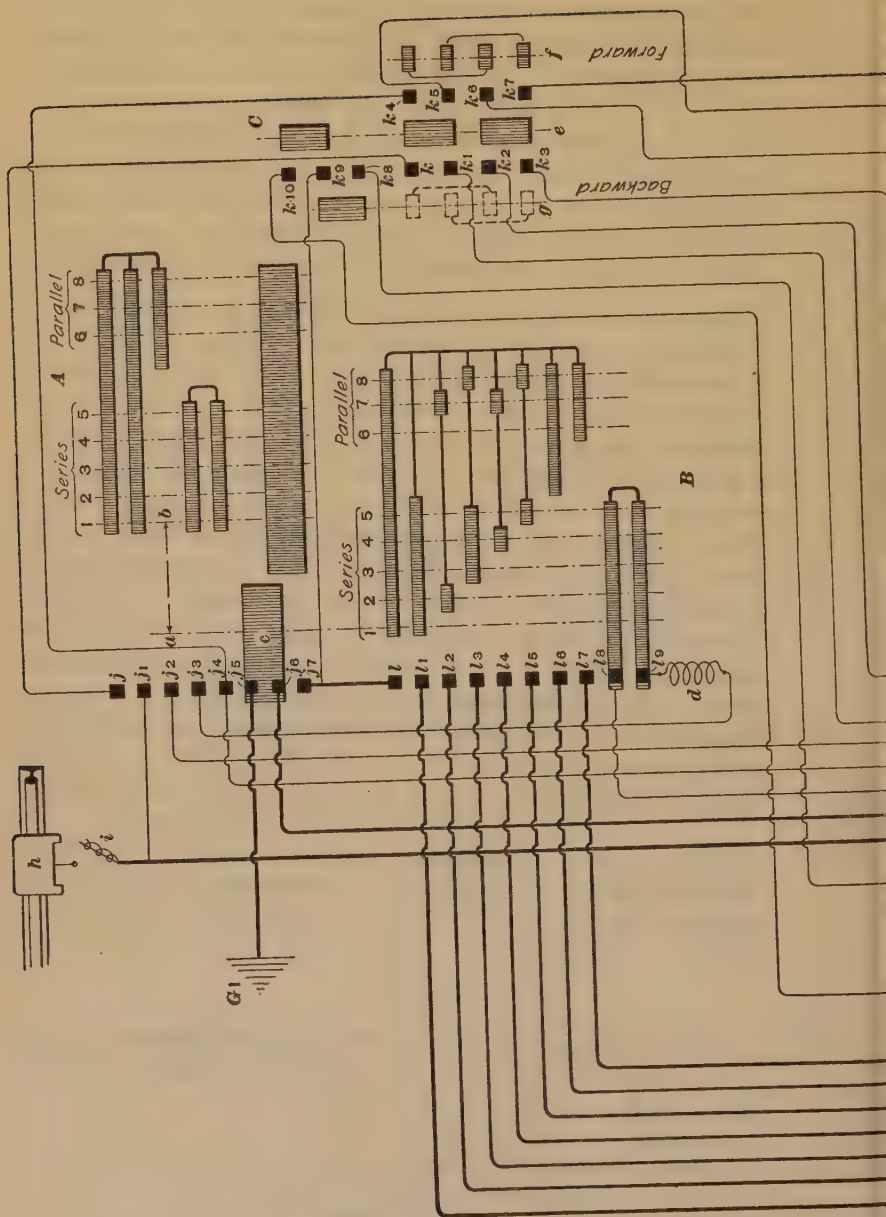


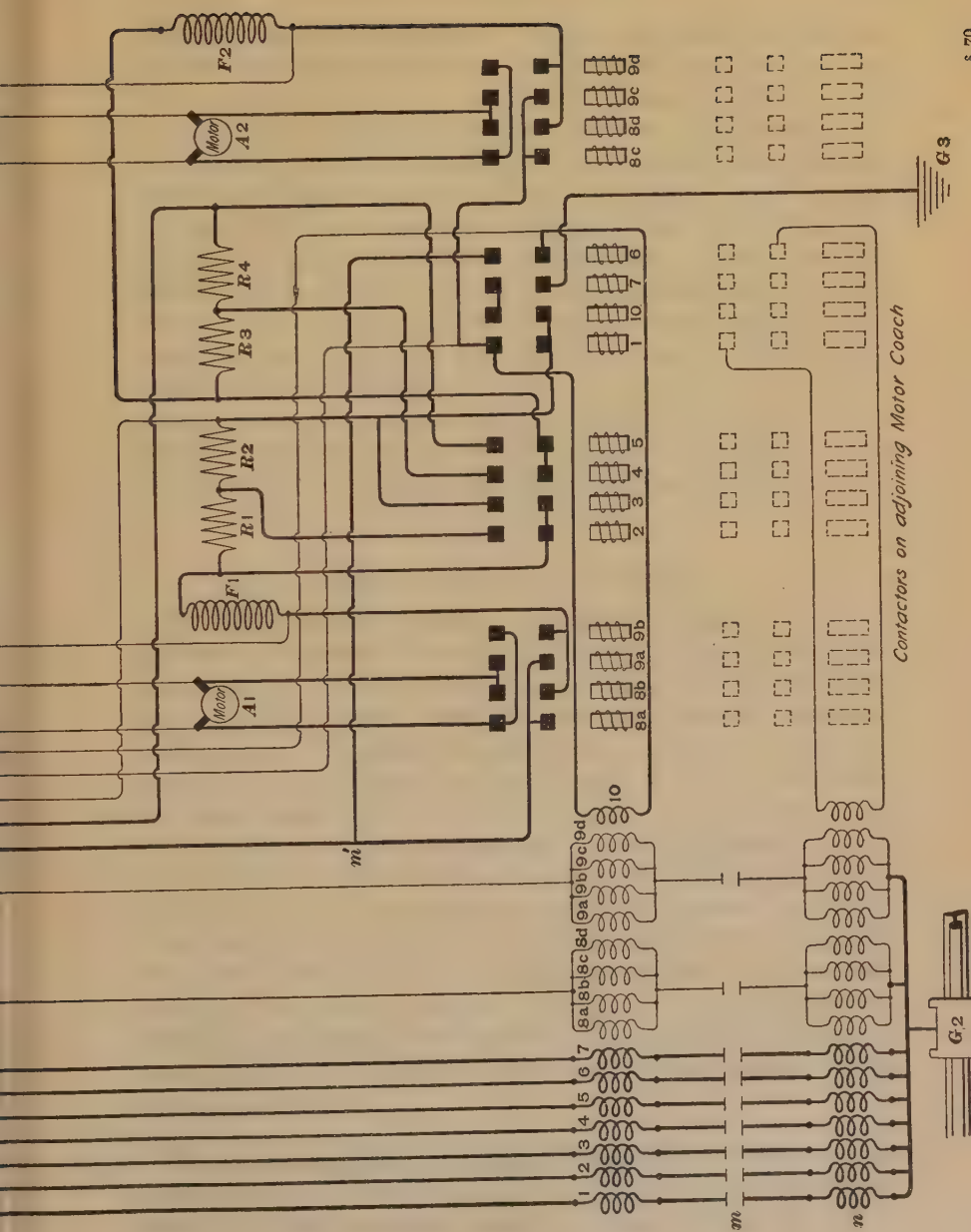
When the contactor barrel *B* is moved to position 2, the first section *R1* of the resistance is short-circuited by the closing of contactor 2, the circuit being as follows: *h-i-8a-A1-8b-F1-2-R2*-contactor 1-contactor 8*c*, and so on as before.

As the contactor barrel *B* is moved to positions 3, 4, and 5, the other sections of the resistance are successively short-circuited, until in position 5 the motors are in full series, the circuit being the same as before, except that all the resistance sections are short-circuited by the closed contactors 2, 3, 4, and 5.

96. Circuits on Parallel Positions.—During the transition of the contactor barrel *B* from position 5, Fig. 44, to position 6, contactors 3 and 5 are first opened, putting all resistance in series with the motors, then contactor 6 is closed, thus short-circuiting motor 1 through *R1* and *R2*, until contactor 1 is opened and opens the circuit of motor 1. The magnetic lock-coil is connected to finger *l9* of the contactor barrel, and is therefore out of circuit in the parallel positions of the contactor barrel, so that contactor 1 can be opened without locking the barrel. Contactor 6 closes the circuit through the operating coil of contactor 10, and contactor 10 closes. When the contactor barrel reaches position 6, so that finger *l7* makes connection, contactor 7 is closed and motor 1 is connected directly to earth, all the control circuits being excited by the current through motor 2. Contactors 6, 7, 8*a*, 8*b*, 8*c*, 8*d*, 10 are closed, and the circuit is as follows: Collector shoe *h*-circuit-breaker *i-m'*-







With the controller on positions 7 and 8, resistance is successively cut out and the motors are in full parallel on-position 8, the circuit being the same as for position 6, excepting that contactors 3 and 5 are closed, thus short-circuiting all the resistance. In switching off, the controller handle is brought back to the off-position, which can be effected by a single sweep of the handle. This movement leaves the contactor barrel *B* in its first parallel position, until the earthing sector *c* on the switch barrel *A* has been brought into connection with fingers *j5* and *j6*. These connect to earth at *GI*, and thus short-circuit all the operating coils and open the contactors, which immediately break the motor circuits all along the train. After this, both barrels move together to the off-position. In this way no circuits are broken at the contactor barrel of the master controller, and consequently no magnetic blow-out is needed.

DIRECT MULTIPLE CONTROL

97. Characteristic Features.—The system of control used on the four-coach trains of the Liverpool and Southport line of the Lancashire & Yorkshire Railway is known as the **Dick-Kerr direct multiple-control system**, to distinguish it from multiple-unit systems. The direct multiple-control system operates the motors on the two motor coaches used in a train by means of two main train cables of four wires each. Three of the wires in each cable are each large enough to carry the current for the motors, and the fourth wire is used to carry current to the operating coils of the reversers, and may therefore be small. There are no contactors except the reverser contactors under the coach bodies, all other contacts being made at the control barrels of the master controllers. Owing to the metallic-shield blow-out coils used on the controllers, it is possible to eliminate arcing at the contact fingers when the circuits carrying large currents are broken.

98. Dick-Kerr DM4 Controller.—In the cab of each of the motor coaches of the Liverpool to Southport trains is a **Dick-Kerr type DM4 controller**, which is shown in Fig. 45. The

controller has two contact cylinders a, a' , one being provided to control the motors of each of the two motor coaches of each train. If the train has but one motor coach, only one of the contact cylinders will be in use. The two cylinders are geared together and are operated by one handle b . The frames containing the insulating partitions c, c' , which fit between the

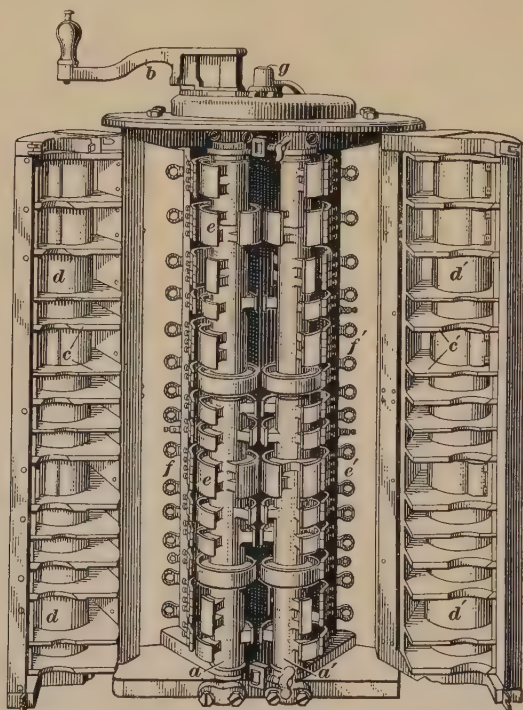


FIG. 45

fingers, are shown opened out so as to expose the contact cylinders. Each of the frames contains an iron core surrounded by a coil of wire which is protected by shields d, d' of copper or other non-magnetic material. The shields come very close to the contact segments e and fingers f, f' , so that when a circuit is broken the arc at the break is transferred to one of the metallic shields d , is forced across the magnetic field set up by the blow-out coil, and is broken at the outside of the shield without

damage to the controller contacts. The shields do not show appreciable wear or burning with ordinary use, even though the controller carries very heavy currents. The handle *g* of the reversing cylinder is constructed in such a manner that it cannot be removed except at the off-position. The reversing and contact cylinders are interlocked, so that if the reversing handle is at the off-position the controlling handle cannot be moved, while if the controlling handle is in any of the operating positions, the reversing handle cannot be moved. On each controller frame there is a terminal connected through a 5-ampere fuse to earth, in order to protect exposed parts of the controller from high pressures.

99. Reversing Cylinder.—On each controller is a small reversing cylinder, which has contacts arranged to supply current to the operating solenoids of electromagnetic reversers under the floor of the coach. The operating solenoids of two reversers are connected in series across the line so that the reversing cylinder must provide circuits for four pairs of reversers, each motor having its own reverser. In Fig. 46, the reversing cylinder *d* is shown between the two controller cylinders *e* and *f*. The contact fingers will bear against the contact strips of the reversing cylinder, as shown on motor coach *I*, when the direction of running is forward, and the corresponding contacts and fingers on the opposite side will be in use for reverse running.

100. Reverser.—The reverser used with the direct multiple-control system is the same as that used on the multiple-unit control system, and is similar in construction to the Dick-Kerr contactor previously described. Each reverser is provided with a metallic-shield blow-out coil, as *II*, Fig. 46, joined in series with the motors, and a number of operating coils which are provided with connections through the reversing cylinder on the controller. Two of the reversers on each motor coach are provided with five contactors in order that the four motors may be connected in two groups of two in series. Where the reverser has only four contactors, one terminal of the motor is permanently grounded, but if five contactors are used, the ground connection of the motor is made through the controller. The coils operating

the reverser contactors are numbered the same as the contactors. In series with the control coils of each pair of reversers are the contacts of two overload circuit-breakers, as *k1* and *k2*, the tripping coil of each circuit-breaker being connected in series with one of the motors so that an overload on either motor of a pair will cause a circuit-breaker to open, and thus cut out the motors by opening the reverser contacts.

101. Wiring Diagram.—In the diagram of connections, Fig. 46, for the Dick-Kerr direct multiple-control system applied to two motor coaches, the controller cylinders are represented in horizontal positions at each end. The corresponding parts of the wiring of the two motor coaches are represented by the same letters, but primes (') are used on all letters and numbers referring to motor coach 2. Each motor and its reverser are marked, as are the resistances, in order to facilitate tracing the circuits. Earth connections are indicated by the letter *G*, followed by numbers and letters to indicate different positions or circuits.

102. Operation of Reversers.—When the reversing cylinder *d* is in the ahead position, as shown in the controller diagram at the left of Fig. 46, current flows from the contact shoe *1*—wire *1*, *1*—ammeter shunt *a*—wire *1*—fuse *b*—switch *c*—contacts of reverse cylinder *d*—wire *2*, *2*, *2*—operating coils *2* and *4* on reverser *2*—operating coils *2*, *4*, and *5* on reverser *1*—contacts of overload release *k1*—overload release *k2*—earth at *G a*. The reversers of motors *3* and *4* are operated from wire *2* in the same manner as the reversers of motors *1* and *2*. The reversers of the second motor coach are operated by wire *2* in the train cable, which connects to wire *3'* on the second coach, to which the operating coils *1'* and *3'* on each reverser are connected. The contactors on each reverser corresponding to the magnet coils which are excited will close, and all the motors are properly connected to receive current through the main-contact cylinders of the controller on coach *1*.

103. Operation on Series Positions.—When the controller cylinders *e* and *f* of motor coach *1*, Fig. 46, are turned so that

the fingers occupy the positions indicated by the dotted line 1, the circuits are as follows: Contact shoes 1, 1-wire 4-ammeter shunt *a*-switch *g*-circuit-breaker *h*-wire 5-blow-out coil *i*-finger *j* on controller cylinder *e*-cylinder contacts to finger *R1*-resistance *R1*-wire 6-

6-coil of overload release <i>k1</i> - reverser blow-out coil <i>l1</i> -con- tactor 2-armature terminal <i>A1-A1</i> -contactor 4-3-field terminal <i>FF1-F1</i> -contactor 5-wire 7-7-	6-coil of overload release <i>k3</i> - reverser blow-out coil <i>l3</i> -con- tactor 2-armature terminal <i>A3-AA3</i> -contactor 4-3-field terminal <i>FF3-F3</i> -contactor 5-wire 7-7-
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finger *m* on controller cylinder *e*-cylinder contacts to finger *R5*-resistance *R5*-wire 8-

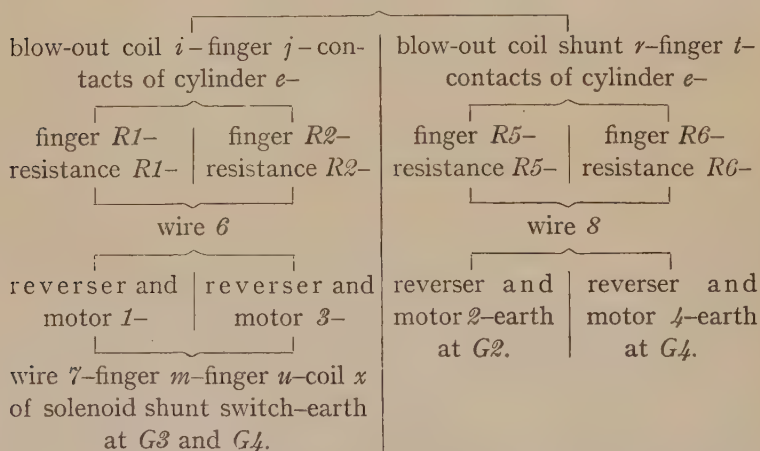
wire 8-coil of overload release <i>k2</i> -reverser blow-out coil <i>l2</i> - contactor 2- <i>A2-AA2</i> -contac- tor 4-3- <i>F2-FF2</i> -earth at <i>G2</i> .	wire 8-coil of overload release <i>k4</i> -reverser blow-out coil <i>l4</i> - contactor 2- <i>A4-AA4</i> -contac- tor 4-3- <i>F4-FF4</i> -earth at <i>G4</i> .
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Advancing the controller handle to positions 2, 3, and 4 successively connects resistances *R2*, *R3*, and *R4* in parallel with *R1*, and resistances *R6*, *R7*, and *R8* in parallel with *R5*. When the handle of the controller is moved so that the controller cylinders are on position 5, all the resistance is short-circuited by fingers *n* and *o*, and the motors are connected in two groups of two in series directly across the line.

104. Controller cylinder *f* on motor coach 1, Fig. 46, makes the same connections as does controller cylinder *e*, but cylinder *f* controls the motors of the second motor coach by means of the train cables. The fingers of the controllers on the rear coach are not resting on any of the segments of the controller cylinders *e'* or *f'*, but the reversing cylinder *d'*, which is at the off-position, is provided with segments which connect fingers *n n'* to *n'*, *o o'* to *m'*, and *m m'* to *o'*. The action of controller cylinder *f* on the first motor coach is therefore as follows: On first position of the controller handle current flows from the contact shoes 1, 1-wire 1-ammeter shunt *a*-wire 1-switch *p*-

circuit-breaker q —blow-out coil i i —finger j j —contacts of cylinder f —finger $RR1$ —resistance $RR1$ on first motor coach—wire 66 —train cable wire 66 —wire $66'$ on second motor coach—contact finger n n' on controller cylinder f' of the second motor coach—contacts on reversing cylinder d' —finger n' —wire $6'$ —reversers and motors $1'$ and $3'$ in parallel—wire $7'$ —contact finger m' —contacts of reversing cylinder d' —finger o o' —wire $77'$ —wire 77 on motor coach 1 —contact finger m m on controller cylinder f —contacts of cylinder f —finger $RR5$ —resistance $RR5$ —wire 88 —wire 88 in train cable—wire $88'$ of motor coach $2'$ —contact finger m m' on cylinder f' —contacts of reversing cylinder d' —contact finger o' —wire $8'$ —reversers and motors $2'$ and $4'$ of the second motor coach in parallel—earth at $G'2$ and $G'4$.

105. Operation on Parallel Positions.—When the cylinders e and f , Fig. 46, of the controller on motor coach 1 are turned to position 6 , the motors of both motor coaches are connected in parallel. The circuits for the motors on motor coach 1 are as follows: Contact shoe 1 —ammeter shunt a —switch g —circuit-breaker h —wire 5 —



The closing of the solenoid shunt switch s parallels the sections of the solenoid shunt r and thus prevents too great a current from flowing through the blow-out solenoid i . On position 7 resistances $R1$, $R2$, $R3$, and $R4$ are in parallel with each other

and in series with motors *1* and *3*, which are in parallel with each other. In like manner the resistances *R5*, *R6*, *R7*, and *R8* are all in parallel and in series with motors *2* and *4*, which are in parallel. When the handle of the controller is moved to its final position, all the resistance sections are short-circuited and the motors are all in parallel across the mains. The motors of the second motor coach are operated by controller cylinder *f* in the same manner as the motors of the first coach are operated by controller cylinder *e*.

CONDUCTOR RAILS AND TRACK CONSTRUCTION

CONDUCTOR RAILS

CONDUCTIVITY PROTECTION AND BONDING

106. Supply Conductors.—Direct current is generally supplied to trains on electric railways by an insulated third rail, and either the track rails or a separate fourth conductor rail forms the return. Overhead trolley wires are sometimes used, in which case the construction is similar to that employed for tramways, unless the voltage of the system and the speed of the trains are very high, in which case a special construction is adopted. Conductor rails may be of the regular shape used for track rails, but are often of rectangular or channel cross-section. Table II gives some particulars of the conductor rails, etc., used on the principal British direct-current railways.

107. Conductivity of Steel Rails.—The specific resistance of steel increases somewhat with the percentage of carbon. The presence of manganese in iron also has the effect of increasing the resistance, but in a varying degree, the higher percentages having a greater effect. By properly adjusting the percentages of carbon, manganese, etc., special steels can be made which have a specific resistance only 7 or 8 times that of copper. For example, steel which, when analyzed, shows percentages not exceeding .15 for carbon, .3 for manganese, .06 for phosphorus,

TABLE II
PARTICULARS OF CONDUCTOR RAILS, INSULATORS, AND MOTORS OF DIRECT-CURRENT ELECTRIC RAILWAYS IN GREAT BRITAIN

Name of Railway	Weight of Third Rail Lb. Per Yd.	Position of Third Rail	Return Conductor	Position of Re- turn Conductor	Third-Rail Insulators	System of Control	Number of Motors on Each Coach or Locomotive	Rated Horse- power of Each Motor
City & South London . . .	40	Between track rails	Track rails		Glass	Series parallel	2	
Liverpool Overhead . . .	70	Centre of track	Track rails		Stoneware	Series parallel	2 and 7	100
Waterloo & City, London .	80	Centre of track	Track rails		Stoneware	Series parallel	2	60
Central London	104	Centre of track	Track rails		Stoneware	B.T.H. multiple unit	2	65
Mersey Tunnel	100	Centre of track	Insulated 4th rail	Centre of track	Vitrified clay	Westinghouse multiple unit	4	100
Great Northern & City, London	80	Outside track	Insulated 4th rail	Opposite side of track	Stoneware	B.T.H. multiple unit	2	125
Liverpool to Southport Section, Lancashire & Yorkshire	70	Outside track 3' 11½" from centre	Uninsulated 4th rail	Centre of track and bonded to track rails	Stoneware	Dick-Kerr direct multiple	4 or 2	150 or 125
Tyneside Lines of North Eastern	80	Outside track 3' 11½" from centre	Track rails		Reconstructed granite	B.T.H. multiple unit	2	125
Metropolitan, London . .	100	Outside track	Insulated 4th rail	Centre of track	Stoneware	Westinghouse and B.T.H.	4	200 or 150
Metropolitan District, London	100	Outside track 3' 8½" from centre	Insulated 4th rail	Centre of track	Stoneware	B.T.H. multiple unit	2	200
Baker Street & Waterloo, London	85	Outside track 6" from track rail	Insulated 4th rail	Centre of track	Stoneware	B.T.H. multiple unit	2	200
Great Western & West London	100	Outside track 1' 4" from track rail	Insulated 4th rail	Centre of track	Vitrified porcelain	B.T.H. multiple unit	4	150
Great Northern, Piccadilly, & Brompton, London	85	Outside track 6" from track rail	Insulated 4th rail	Centre of track	Vitrified porcelain	B.T.H. multiple unit	2	200
Charing Cross & Hampstead, London	85	Outside track 6" from track rail	Insulated 4th rail	Centre of track	Vitrified porcelain	B.T.H. multiple unit	2	200

·06 for sulphur, ·05 for silicon, has a resistance about 8 times that of copper. On the Central London Railway the third-rail conductor has a resistance $7\frac{1}{2}$ times that of copper of equivalent area.

108. Protection of Conductor Rails.—Near stations and at crossings it is necessary to protect the third, or conductor, rail so as to reduce the danger to anyone who may walk on to the track from the station platform or the crossing. The method generally used in Great Britain is shown in Fig. 47 (a) and (b). Planks *a* are bolted to the distance pieces *b*, which rest against the rail so that the top edges of the planks stand several inches above the top of the rail and at a sufficient distance from it to clear the collector shoe. In the United States this method of protection gives more trouble than in Great Britain, because of

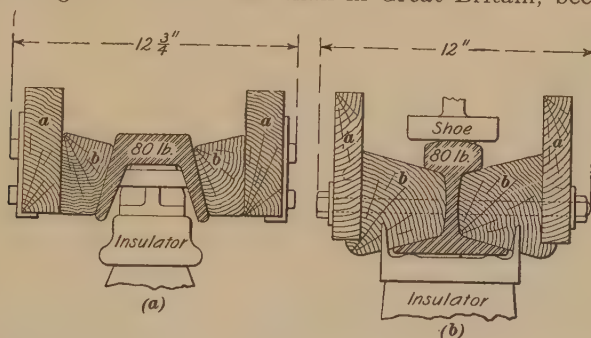


FIG. 47

snow and sleet which sometimes form on the top of the conductor rail. The planks are therefore fixed over the top of the conductor rail and current is picked up by means of a shoe which projects under the protective covering of the rail.

109. Protected Bond for Conductor Rail.—Bonding is the method generally used for connecting the sections of conductor rails, because, owing to the rails being uncovered, there would be trouble with expansion and contraction if the joints were welded. The currents used are much greater than in tramway work, and therefore the bonds must be of greater section, but otherwise they are similar. Fig. 48 shows the protected type of bond as used on a conductor rail having the same shape as the track rails. The bond is made of copper strips *a* cast into solid copper

ends *b*, which are expanded tightly into the web of the rail. After being fixed in position the bonds are covered by the fish-plates *c*. In some cases the terminals of rail bonds are electrically welded to the rails, instead of being expanded into holes drilled in the web or flange of the rail.

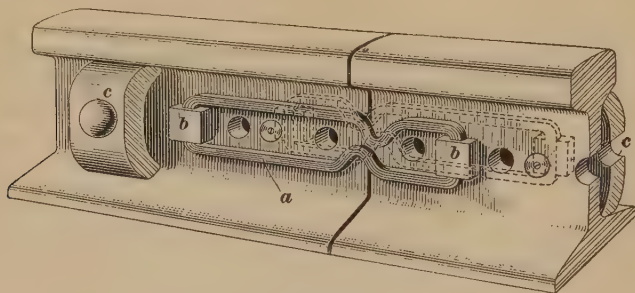


FIG. 45

110. Unprotected Bonds for Conductor Rails.—Owing to the fact that a conductor rail is usually at a potential of 500 volts or more above the earth potential, the bonds cannot be removed

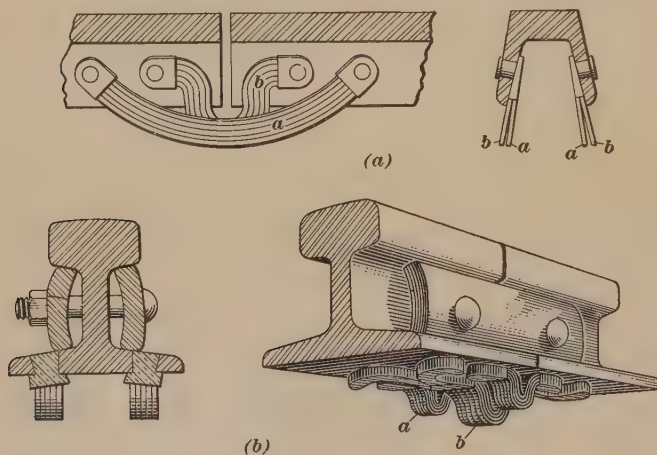


FIG. 49

easily or safely, and therefore need not be protected by fish-plates to prevent their removal by unauthorized persons. The unprotected type of bonds can be made more flexible than the

protected type, and therefore will permit of greater movement between the adjacent rail ends without injury to the connections. In Fig. 49 (*a*) is shown a double flexible bond for a channel conductor rail. The bond consists of two flexible conductors *a* and *b* joined to terminals which are expanded into the flange of the rail. Fig. 49 (*b*) shows a form of flexible bond fitted to the flange of a conductor rail. As in the previous case, there are two shapes of bonds used, as shown at *a* and *b*. The cross-sectional view shows the way in which the bond terminals are expanded into the rail flange.

111. Feeder Connections.—In all cases where a break is made in the conductor rail, the ends must be joined by means of an underground cable. Various methods of running the cable are used. In the method shown in Fig. 50, each end of the cable is carried through a heavy porcelain insulator *a* set in an iron pipe *b*. The strands of the cable *c* are soldered into a terminal casting *d*, and after the lower part of the insulator has been plugged with hemp the space is filled with insulating compound to prevent moisture from entering and injuring the paper insulation of the cable, which, in this case, has a lead sheath covered with jute treated with asphalt. A brass cap *e* is bolted to the cable terminal, and from it two flexible bonds are connected to the rail.

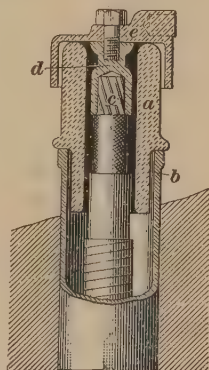


FIG. 50

JUNCTIONS

112. Continuity of Current Supply.—At crossings and junctions the presence of the third rail causes difficulties which are not experienced in overhead systems. It is, of course, impossible to preserve the continuity of the conductor rails at junctions. On tube railways in Great Britain, where bus-lines connecting the collector shoes on different motor coaches are not permitted, the circuit must often be broken at junctions. Where a bus-line is provided, it is practicable in most cases to bridge the

gap, the shoe on the forward car making contact with the rail before the shoe on the rear car has reached the gap. In order that the shoe may come into contact with the conductor rail without a jerk, the rail is tapered on each side of every gap,

and by this means the shoe is gradually raised. In many cases the vertical travel of the shoe is $\frac{3}{4}$ inch on each side of its mean position, and a taper of 1 in 24 is commonly adopted for the rails on each side of a gap; with this slope the length of the tapered portion of each rail must therefore be 18 inches.

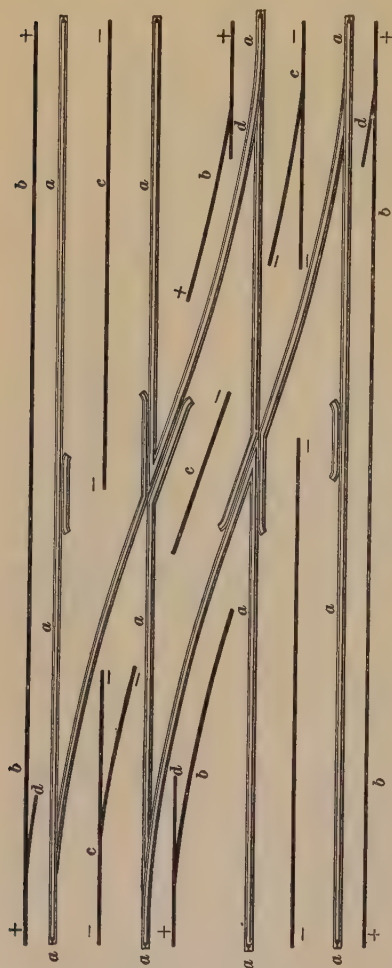


FIG. 51

113. Arrangement of Conductor Rails at Cross-Over.

The arrangement of third and fourth, or supply and return, conductor rails at a cross-over from one track to another is shown diagrammatically in Fig. 51, in which the four track rails are marked *a*, the positive conductors or third rails *b*, and the return conductors or fourth rails *c*. At four points there are special attachments *d*, forming sloping approaches to the rails *b*, whereby the collector shoes when approaching the rail are led

up to the surface of that rail. Without these attachments the shoe would simply collide with the side of the rail, and one or

the other would be damaged. The positive conductor rails *b* are usually about 3 inches above the track rails, and the return conductor rails are about $1\frac{1}{2}$ inches above the track rails, so that the contact shoes will clear the track rails at cross-overs. If a coach or locomotive were not provided with collector shoes on both sides of the track, there would sometimes be difficulty in supplying current to the motors at cross-overs.

INSULATION OF CONDUCTOR RAILS

114. Forms of Insulators.—The conductor rail should be thoroughly insulated from the track rails and ground by being mounted on insulators that are strong mechanically, and which allow the conductor rail freedom for expansion and contraction. In some cases insulators made of specially treated wood, provided with an iron cap on which the rail rests, have been used, but usually the insulators are of special insulating material, such as stoneware or reconstructed granite, the latter being concrete formed from crushed granite and cement.

Fig. 52 shows a type of insulator for a conductor rail in which the insulating material is reconstructed granite. Side motion of the rail is prevented by the lugs *a* and *b*, which are held in position by a bolt *c*, which passes entirely through the upper portion of the insulator. The insulator is held to the sleeper by means of the bolted corner castings *d*. The lugs holding the rail allow a certain amount of play, as the weight of the rail is sufficient to hold it in place, and, if too tightly fastened, heavy stress, due to the expansion and contraction of the rails, is thrown on the insulators.

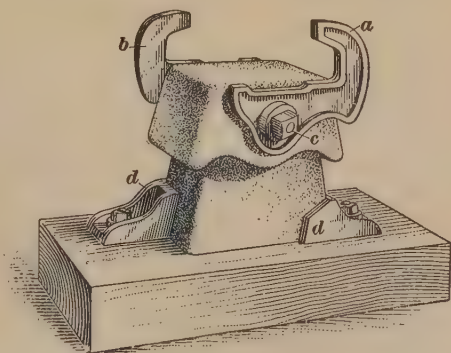


FIG. 52

115. Stoneware Insulators.—In Great Britain insulators made of vitrified stoneware have been largely used. In Fig. 53 is shown

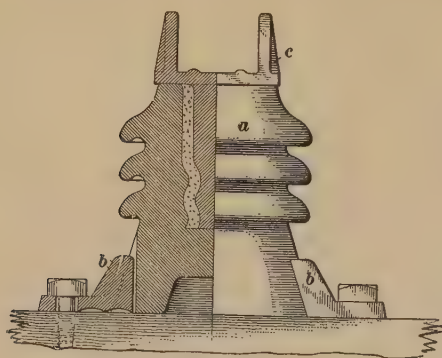


FIG. 53

a partly sectional view of a Doulton pedestal type of insulator. The stoneware part *a* has three petticoats to shed off any moisture, and it is held from moving on the sleeper by the malleable iron castings *b*. The conductor rail is held in position by a cap or chair *c* of suitable shape, made of malleable iron,

provided with a stem which is cemented into a recess in the insulator.

Fig. 54 shows a Doulton fourth or negative return conductor, rail insulator of the type used on the Metropolitan & District Railway of London. It is much shorter than the third-rail insulator, because the potential of the return conductor is nearly the same as that of the earth, and there is very little tendency for leakage to occur. The rail is held in position by lugs on an iron cap *a* which fits over the stoneware body *b*. The base *c* is provided with three holes for screws to fasten it to the sleeper

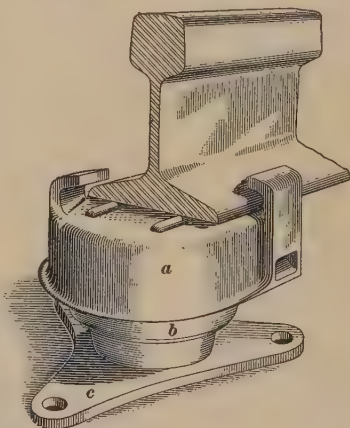


FIG. 54

and with a stem, which is cemented into a hole in the centre of the stoneware body *b*. If the rail expands, it slides on the ribs provided on the cap of the insulator, and thus avoids producing undue stresses in the insulating material. Side motion of the rail is prevented by the lugs.

TRACK CONSTRUCTION

116. Track Rails.—For track rails the first requirement is, of course, mechanical strength, and when used to carry the return current their electrical properties must be subordinate to mechanical qualities. The resistance of the track may be made low enough to keep the voltage drop within a reasonable limit if the joints are carefully bonded. It is usual, in addition to the bonds at the rail joints, to run an extra conductor which connects to the two track rails at frequent intervals and aids in equalizing the flow of current. Since high-conductivity iron does not possess sufficient strength, the track rails have usually a specific resistance about 12 times that of copper, and manganese steel, which is used for special work, has a still higher resistance.

117. Board of Trade Regulations.—The rules given by the Board of Trade for governing the construction and arrangement of the permanent way and stations of tube railways are as follows :

1. Sleepers to be of hard wood, not creosoted, and to be laid in concrete or ballast, and covered with a layer of gravel or finely broken stone free from dust, the ballast to be finished to a level surface so as to form a convenient roadway for passengers in case of emergency. If ballast is not used, the space between the rails to be covered with granolithic slabs, or slabs of a similar material, to form as wide a roadway as possible for passengers. No timber planks to be used.

2. Tunnels to be provided with lights capable of being turned on from the stations at either end of each section, and, if necessary, at some intermediate points. The lighting circuits to be independent of the traction supply.

3. Separate entrances to and exits from each platform of the stations to be provided, and to be situated as nearly as possible in the middle of the platforms.

4. All stairways, passages, and exits from the stations to be conspicuously lighted. Not less than 25 per cent. of the lights in these places to be supplied from independent source. If necessary, the exits to be made more conspicuous by the use of coloured lights in addition to white lights.

5. Platforms not to be made of wood, and woodwork to be eliminated as far as possible from signal boxes, lifts, offices, etc., below ground.

6. Efficient hydrants, hose, and fire-prevention appliances to be provided.

7. Ventilating ways to be provided wherever possible from the station and the tunnels to the surface.

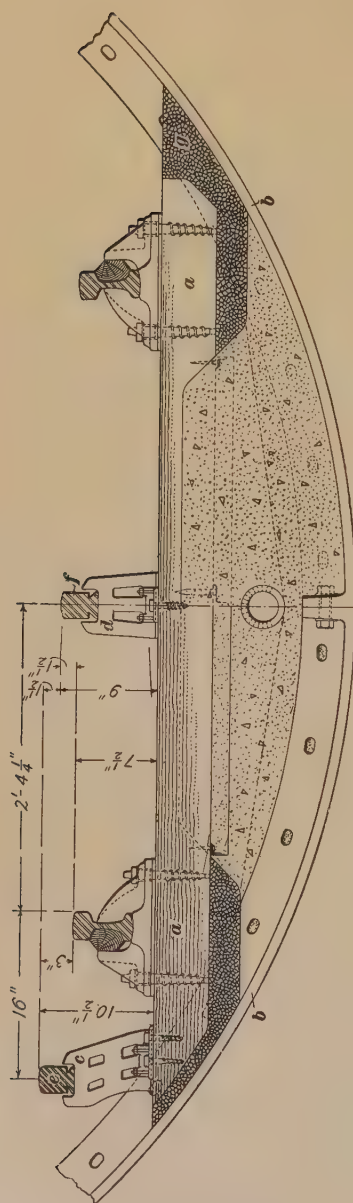


FIG. 55

118. Track Construction for Tube Railways.—The tunnels of the tube railways in London are lined with cast-iron segments *b* bolted together and made water-tight with rust cement. As the space available is very limited, there is not room enough for the usual ballast and sleeper construction of the track. When the first tube railways were built, cross or longitudinal sleepers resting against the walls of the tunnels were used, but in some cases this construction caused the vibration of passing trains to be communicated to neighbouring buildings. The special construction shown in Fig. 55, which shows a partial cross-section of the Baker Street & Waterloo Railway, was therefore adopted. The bottom of the tube is filled with concrete, and sleepers of hard wood are laid in it, the ends projecting as shown at *a*. Under these projecting ends crushed granite is packed to give the roadbed elasticity. Some of the sleepers are long and carry stoneware insulators *c* and *d*, which

support the third and fourth conductor rails *e* and *f*. These conductor rails weigh 85 pounds to the yard, and in order to give less jar or vibration on the insulators, felt pads are placed between the insulators and the sleepers.

119. Standard Dimensions.—As it is desirable that, on main-line railways, a train built for one railway shall be able to run on any other, a conference of British railway companies was held in 1903 to consider the best position for conductor rails, so as to secure uniformity. Fig. 56 shows the arrangement adopted. The track rails are indicated at *a*, the third rail, or

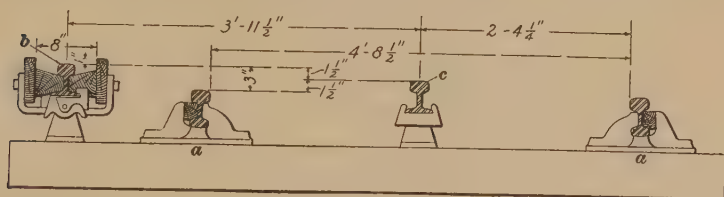


FIG. 56

supply conductor, at *b*, and the fourth rail, or return conductor, at *c*. Both the third and fourth rails are on insulators, the top of the third rail being 3 inches and the top of the fourth rail being $1\frac{1}{2}$ inches above the track rails. On many railways this standard arrangement has been adhered to, but in the confined space of some of the tube railways in London the dimension between the third rail and the centre of the track is less than 3 feet $11\frac{1}{2}$ inches. On the Liverpool & Southport branch of the Lancashire & Yorkshire Railway the fourth rail is uninsulated, and each rail length is bonded to the track rails.

ALTERNATING-CURRENT RAILWAYS

(PART 1)

THREE-PHASE RAILWAYS

CHARACTERISTICS OF THREE-PHASE MOTOR

DEVELOPMENT OF ALTERNATING-CURRENT RAILWAYS

1. Introductory.—The application of electric propulsion to long railway lines has brought forth conditions that require a more economical and efficient system of current distribution than is possible with direct current at the usual voltage of 650 or less. The cost of copper conductors required to transmit very large currents over long distances, with a reasonable loss of power in the transmission system, prohibits their use. This has led to the development of the high-tension alternating-current generating station in conjunction with substations to convert the alternating current to direct current, from which direct current at a pressure of about 600 volts is supplied to the railway lines. The substation machinery is expensive, and a number of skilled attendants are necessary in each station. As the size of the train equipments increased, the current on the low-tension direct-current circuits became excessive, and the safe limit of the carrying capacity of the trolley wire was exceeded. The third-rail system is extensively used and a large current may be carried by the conductor rail, but it is not advisable to place the

supply conductors so near the ground when alternating current at high voltage is employed.

2. If a high-voltage alternating current is supplied to the trolley line and then utilized for propelling trains by means of alternating-current motors, the trolley wire may be of moderate size, even though its length is great and the train load heavy. With alternating current in the transmission lines from the generating station to the substations and in the trolley lines, the substations need contain only static transformers and auxiliary switching apparatus ; that is, no moving machinery is necessary. The substation equipment is then of comparatively low cost, and little, if any, attendance, except regular inspection, is required.

3. **General Construction.**—In principle, the three-phase railway motor is similar to the ordinary stationary three-phase motor, but structurally there are many points of difference. The railway motor is subject to severe vibration ; consequently, the air gap is made somewhat longer and the shaft stiffer than for a stationary motor, and the bearings are made extra large. The air gap cannot be greatly increased, because of the reduction in power factor and overload capacity which results. The percentage of space allowed for insulation is also extra large, to allow for excessive mechanical as well as electrical stresses. For considerations of space and weight, the magnetic and current densities in traction motors are generally higher than those in motors in stationary working. The slip is therefore usually higher in traction motors. There are also various other changes due to the special methods of working the motors.

4. **Use of High Voltage.**—The voltage which can be used directly across the stator windings of three-phase traction motors is limited only by the insulation of the windings. The voltage on the trolley wires is limited by the possibility of sparklessly collecting the current from the wires. In practice, pressures of 3,000 volts, 6,600 volts, and even 10,000 volts between the lines have been successfully employed, the motors and controlling apparatus operating satisfactorily, and the current being collected

by means of specially designed bow collectors without any harmful sparking, even at very high speeds. It is, of course, possible to use static transformers to reduce the voltage for the motors; this increases the weight and cost of the locomotive, and, for pressures up to 10,000 volts, transformers have not been found to be necessary.

5. Choice of Frequency.—The frequency at which current is supplied has a considerable effect on the drop occurring in the trolley wire and track rails. The higher the frequency, the greater will be the drop with a given current; the drop depends also on the shape and material of the conductor as well as on its sectional area and length, and is greatest with iron conductors. Therefore, if the steel track rails are used as one of the conductors, the voltage drop in them must be carefully considered. Some years ago twenty-five cycles per second was considered a very low frequency, but the tendency is now to make fifteen cycles per second the standard for railway working. The Simplon Tunnel Railway and the Valtellina Railway work with a supply at sixteen and fifteen cycles per second, respectively.

BEHAVIOUR AS ASYNCHRONOUS MOTOR

6. Speed.—The induction motor is the type used on three-phase railways, as it is the only type of polyphase motor which is capable of giving the large starting torque necessary for traction work. The speed of an induction motor is practically constant at all loads. Under working conditions, the maximum variation for a traction motor does not exceed 8 per cent. of the synchronous speed, whether the train is running up a gradient, on the level, or down a gradient. The synchronous speed of an induction motor is the speed at which the magnetic poles rotate round the stator core. The rotor runs at a speed slightly less than the synchronous speed when the motor is delivering mechanical power to the shaft. The amount that the speed of the rotor differs from the synchronous speed is called the slip. In Fig. 1, curve *a* shows that the speed of a certain 64-horsepower motor varies from nearly 600 revolutions per minute at no load to 567 revolutions per minute at full load.

7. Power Factor.—The induction motor has a power factor which is invariably less than unity, whether the speed is below synchronism, and the machine is acting as a motor, or above synchronism, and the machine is acting as a generator. At small loads the power factor is low, and gradually increases with the load up to a certain point, after which it falls off again. The point at which the maximum power factor occurs varies with

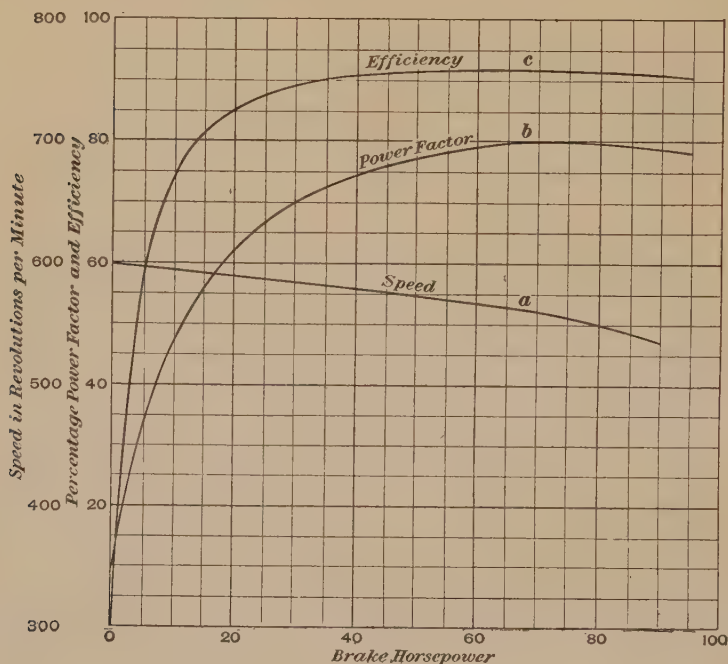


FIG. 1

the design of the motor from $\frac{3}{4}$ to $1\frac{1}{4}$ full load. In Fig. 1, curve *b* shows that the power factor for a certain 64-horsepower motor is slightly less than 80 per cent. at full load and increases until the load exceeds 76 horsepower, after which it falls.

8. Torque and Efficiency.—The motor has a definite maximum torque, so that if the resistance to motion is greater than a certain value the motor will stop. This maximum depends

primarily on the design and magnitude of the motor, and secondarily on the voltage and frequency of the supply. Any fall in the voltage or any rise in the frequency will reduce the maximum available torque which the motor can exert.

The speed corresponding to any given torque depends on the resistance of the secondary windings ; if arrangements are made, by means of slip-rings and external resistances, to vary the resistance of the secondary windings, the speed of the motor can be regulated to any value between the maximum and zero. Such regulation involves, however, electrical losses in the resistances, and reduces the efficiency in approximately the same ratio that the speed is reduced.

The efficiency of the motor is usually at its maximum somewhere near full load, but does not vary to any great extent between $\frac{3}{4}$ and $1\frac{1}{4}$ load. In the particular case of a 64-horse-power motor, curve *c*, Fig. 1, shows a maximum efficiency of 92 per cent. and but small variation for a wide range of loads.

BEHAVIOUR AS ASYNCHRONOUS GENERATOR

9. **Advantage of Regeneration.**—It has already been pointed out that the three-phase induction motor is essentially a constant-speed machine, and tends to run always within a very small margin of synchronous speed. Below this speed the motor is making an effort to accelerate, and above this speed, to retard. Acceleration involves the supply of energy to the accelerated body ; retardation involves the extraction of energy from the retarded mass. If a car fitted with three-phase induction motors is running down a gradient, the speed of the motors may be brought above synchronous speed, in which case they will act as generators, supplying electrical energy to the line and absorbing mechanical energy from the driving wheels. It was found that the trains on the Swiss mountain railways could be kept in check by the induction motors alone acting as generators, thus making the use of mechanical brakes unnecessary. The system of returning energy to the line by making the car drive the motors as generators when descending gradients is called a **recuperative, or regenerative, system**.

10. On the mountain railways previously mentioned the regenerated energy cannot always be usefully applied, because there are usually only two trains, one of which may not always be ascending when the other is descending.

In systems where there are a considerable number of trains running, the recuperative, or regenerative, system has been used with great success and economy. Not only do the descending trains generate energy, which goes to help other trains that may be ascending, but also, when stopping, part of the energy that would otherwise be wasted in wearing away the wheels and brake blocks is saved.

11. The regenerative property of the three-phase motor sharply differentiates it from motors working with single-phase alternating current and from ordinary series-wound direct-current railway motors.

With the three-phase motor no special arrangements of any kind are necessary for regeneration. If a train, after running at a steady speed on the level or up-hill, comes to a descending gradient, the speed will rise slightly and the motors will regenerate without any change whatever in the electrical circuits.

As an example of the value of regeneration or recuperation, the case of a train weighing 300 tons and travelling on a 2 per cent. gradient may be cited. When running up the grade at $38\frac{1}{2}$ miles an hour, the input was 1,490 kilowatts, and when descending at a slightly higher speed, the train regenerated 660 kilowatts.

12. **Motor and Generator Characteristics.**—The application of the regenerative principle is illustrated by the curves in Fig. 2, which are plotted from the results of a test on a Ganz three-phase railway motor. The half of the diagram to the right of the ordinate OO gives the curves for the machine as a motor, and the left half shows its performance as a generator. The curve a shows the speed, in miles per hour, of the locomotive and train driven by the motor, plotted against the pull on the drawbar, in pounds. Curve a' shows the speed of the train when running down a gradient and giving a retarding thrust or negative pull on the drawbar, as shown by the horizontal scale.

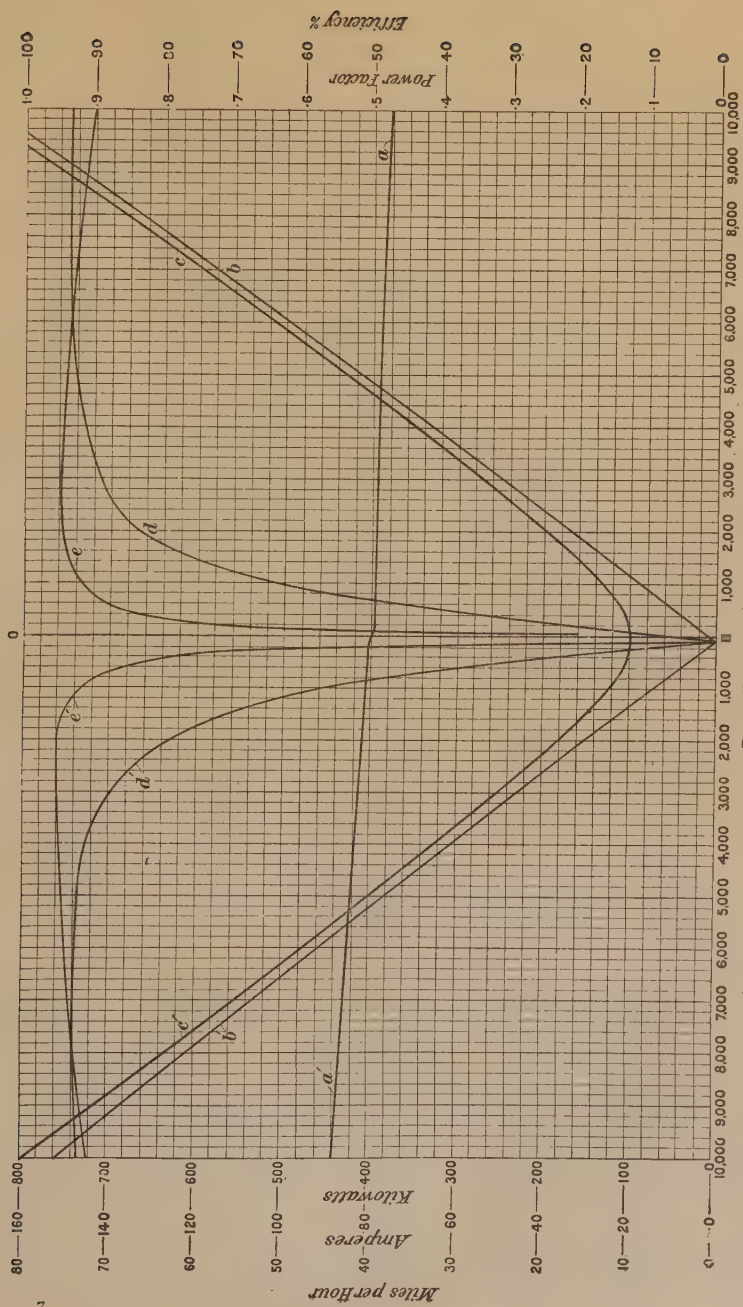


FIG. 2
Draw-Bar Pull in Pounds.

The curves a , a' show that when the machine works as a motor the speed is always below 40 miles per hour and the slip is positive; when it works as a generator the speed is above synchronism and the slip is negative, the input also being negative. The negative value of the input signifies that energy is being returned by the machine to the line.

13. The curves b , b' in Fig. 2 show the number of kilowatts absorbed or returned by the machine, the part of the curve to the right of the ordinate 00 representing power used, and that to the left the power regenerated. The current input and output are given by the curves c and c' , respectively, and the power factor and efficiency when motoring and regenerating are given by the curves d , d' and e , e' , respectively. The curves show that when the locomotive and train are running down-hill at 42 miles per hour, a total current of 71 amperes is being returned to the line, this corresponding to a regeneration of 355 kilowatts and a thrust or negative pull on the drawbar of 4,400 pounds. Although the kilowatt curves b , b' fall to zero, the current curves c , c' do not do so; this is because an exciting current of nearly 20 amperes is required to maintain the magnetism of the motor. If the pressure across the terminals of an induction motor fails when it is running as an asynchronous generator the generating action ceases, no matter how fast it may be driven, because there is no current available to maintain the magnetic field. For this and other reasons the regenerative action must not be relied on too greatly for a braking effect, but mechanical brakes must be provided for emergencies.

TYPICAL SHORT RUN WITH SIMPLE THREE-PHASE MOTOR

14. **Energy Consumed in Accelerating.**—In the simple type of three-phase motor, the input to the motor corresponding with any given pull is the same, whatever the speed. Hence, if a train is fitted with ordinary three-phase motors having rheostatic control, and not having any of the arrangements for saving energy which are usually employed, the input to the motors during the acceleration period must be kept constant. Fig. 3 shows the speed, distance, and kilowatts-input curves for a train

in which each motor has to deal with a total weight of 40 tons and the rate of acceleration is assumed at 1 foot per second per second. During the whole time that the train is accelerating, the input per motor is kept constant at 305 kilowatts until the train has reached a speed of $38\frac{1}{2}$ miles per hour. At this moment

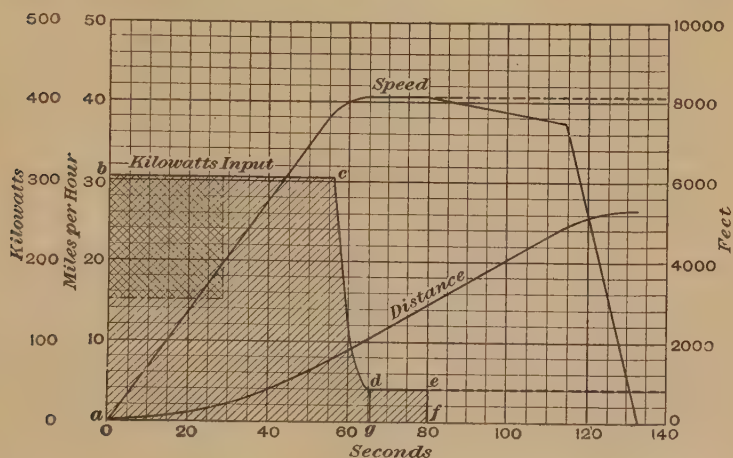


FIG. 3

the external rotor resistances have been reduced to zero, that is, the rotor windings have been short-circuited. As the rate of acceleration decreases, the pull of the motor falls off, until a balance is reached between pull and tractive resistance, at a speed of $40\frac{1}{2}$ miles an hour, when the input to the motor has fallen to 40 kilowatts.

15. Assuming a constant voltage of supply and a level track with no curves, the input remains at 40 kilowatts, as shown by *d, e*, Fig. 3, until coasting commences after a period of 80 seconds from the start. The brakes are applied after coasting for 34 seconds, and the train comes to rest after running for a total time of 133 seconds. The area *a b c d e f* represents the energy input, and it will be noticed that the bulk of it is used up in accelerating. If the run had been 5 miles instead of 5,300 feet, as given by the distance curve, then the area *d e f g* would have extended forwards, as shown by the dotted lines, for nearly

the whole run, and the area $a b c d g$ would have become a much smaller proportion of the whole. This shows that for long runs the energy used in accelerating is not such an important matter as in short runs, and the waste of energy in resistances is not excessive. The connections may be arranged so that when two motors are used on a locomotive or motor coach the input during the period of acceleration may be reduced by the amount indicated by the cross-hatched portion of the area representing the energy input.

SPEED CONTROL OF INDUCTION MOTORS

RHEOSTATIC SYSTEM

16. Effect of Resistance in Rotor Circuit.—If resistance is inserted in the rotor circuit of an induction motor, the slip of the rotor will be increased, as it will require an increased E.M.F. to force the necessary current through the rotor conductors. The torque remains constant if the value of the rotor current and the magnetic flux do not change. The curves in Fig. 4 show the results of varying the resistance in the rotor circuit of a 67-horsepower three-phase induction motor. Curve a shows the variation in speed as the load or torque is varied, and the total resistance R in the secondary winding is equal to the resistance R_o of the winding alone. The no-load speed is nearly 600 revolutions per minute, and this falls off gradually until, at full-load torque of 592 pound-feet, the speed is 567 revolutions per minute. If an external resistance equal to that of the rotor windings is inserted in the rotor circuit, that is, $R = 2R_o$, the speed at which any given torque is obtained is reduced. Full-load torque of 592 pound-feet is obtained in this case at a speed of 530 revolutions per minute, as shown by curve b . Curves c , d , e , and f respectively show the relations of speed and torque for conditions where $R = 4R_o$, $R = 6.45R_o$, $R = 12R_o$, and $R = 25R_o$. The maximum torque obtainable from the motor is 800 pound-feet, this being indicated by all the curves turning over at this point.

17. The rheostatic method of control of the speed of induction motors is extremely wasteful of energy and can only be used for cases where changes of speed are very seldom necessary, and where extreme simplicity is of more importance than high efficiency. If, for example, it is desired to reduce the speed of

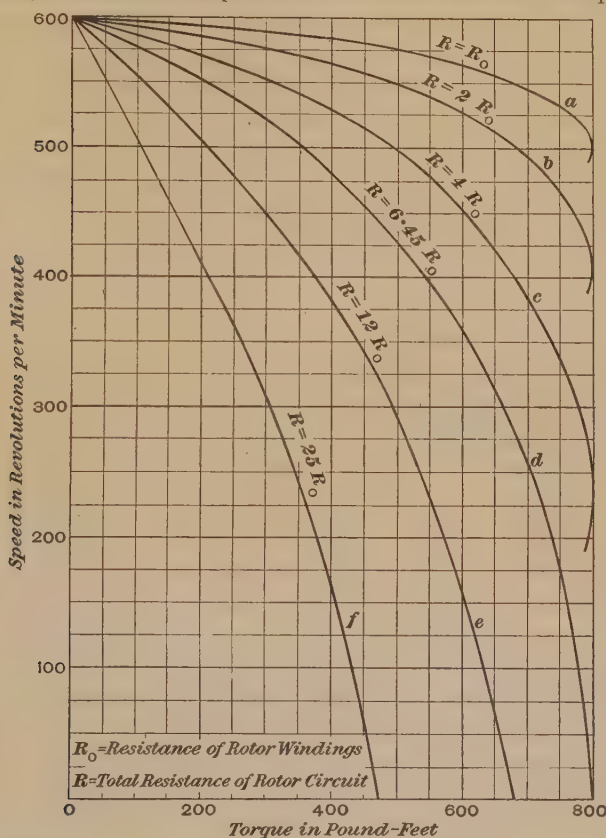


FIG. 4

a train to half its normal value by the use of resistances in the rotor circuit, then approximately half the energy supplied to the motor is wasted in the rotor circuit. In the majority of cases, the loss of energy that would be occasioned by this method of control is too serious to allow of its use, and one of the more modern methods which are about to be described is adopted.

CASCADE SYSTEM OF SPEED CONTROL

18. **Characteristics of Cascade System.**—The cascade system of controlling the speed of induction motors enables full advantage to be taken of the regenerative action of the machines. The motors retain their characteristic of constant speed, yet more than one constant speed is possible without rheostatic losses. Also, regeneration is possible, not only above the normal full speed, but over a fairly wide range of speeds below it. These improvements have brought the three-phase system into such a state of perfection that it can stand comparison, as far as energy consumption is concerned, with any other system.

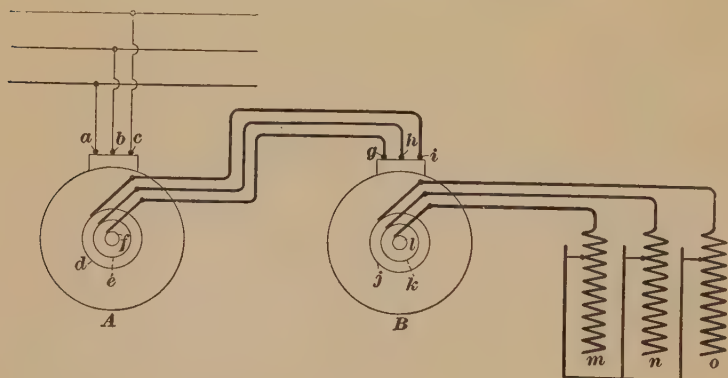


FIG. 5

19. **Cascade Connections of Motors.**—Three-phase motors may be connected in **cascade**, or **concatenation**, as it is sometimes called, as shown in Fig. 5. The three-phase supply is connected to the stator terminals *a, b, c* of the first, or *primary*, motor *A*, and the rotor windings of this motor are connected through the slip-rings *d, e, f* to the stator terminals *g, h, i* of the second, or *secondary*, motor *B*. The rotor windings of the second motor are connected through the slip-rings *j, k, l* to the resistances *m, n, o*.

If the two motors are mechanically coupled to car wheels of the same diameter, then the speeds of the two motors must be the same. The combination will run at such a speed that the frequency of the rotor currents in the first machine will be of

the proper value to supply the stator of the second machine. If the motors have the same number of poles, the combination will then run at half the synchronous speed of each motor separately. The synchronous speed of the pair of motors in cascade is called the **speed of cascade synchronism**, and at this speed the frequency in the rotor of the second motor is zero.

20. Compound Three-Phase Motors.—In Fig. 5, the rotor of the first motor is shown connected to the stator of the second. It makes no difference to the operation, however, if the connections are as shown in Fig. 6, in which the supply mains are connected to the stator terminals *a*, *b*, *c* of the first

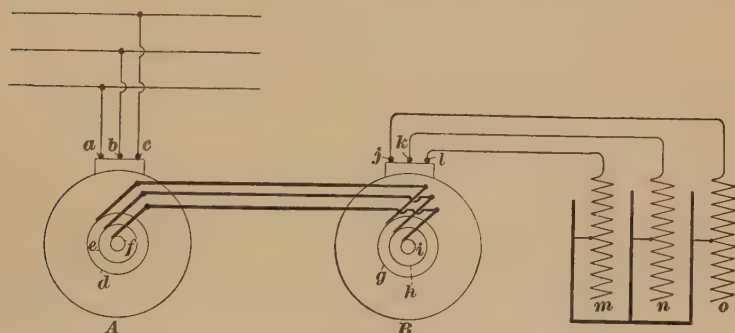


FIG. 6

motor *A*, and the rotors of the first and second motors are connected together through the two sets of slip-rings *d*, *e*, *f* and *g*, *h*, *i*. The stator terminals *j*, *k*, *l* of the second motor *B* are connected to the starting resistances *m*, *n*, *o*. The two motors can be connected together on the same shaft and the slip-rings *d*, *e*, *f* and *g*, *h*, *i* done away with, the connections being carried through from the rotor of motor *A* to that of motor *B*. The stators are then usually enclosed in the same housing. Motors constructed in this way are generally known as **compound three-phase motors**. They need not necessarily be arranged for cascade working.

21. Speed of Cascade Synchronism.—A formula for calculating the speed of cascade synchronism, when the frequency of

supply and the numbers of poles on the first and second motors are given, can be deduced as follows :

Let P = number of poles on first motor ;

P' = number of poles on second motor ;

$\sim$ = frequency of supply, cycles per second ;

N = actual speed of combination, revolutions per minute.

Then, the normal synchronous speed of the first motor is $\frac{120 \sim}{P}$.

The speed with which the magnetic field of the first motor cuts the rotor is given by the difference between the speed of the field and the speed of the rotor, and is $\frac{120 \sim}{P} - N$. The frequency

in the rotor of the first motor is therefore $\left(\frac{120 \sim}{P} - N \right) \frac{P}{120}$,

and this is also the frequency in the stator of the second motor.

The speed at which the field rotates in the second stator is therefore

$$\left(\frac{120 \sim}{P} - N \right) \frac{P}{120} \times \frac{120}{P'} = \frac{120 \sim - NP}{P'}$$

The difference between the speed of the field and the speed of the second rotor is $\frac{120 \sim - NP}{P'} - N$, and the frequency in

the second rotor is $\left(\frac{120 \sim - NP}{P'} - N \right) \frac{P'}{120} = \sim - \frac{N(P + P')}{120}$.

At the speed of cascade synchronism, the frequency in the second rotor is zero. Thus, $\sim - \frac{N(P + P')}{120} = 0$, and the expression

for the speed of the combination becomes

$$N = \frac{120 \sim}{P + P'}$$

22. Comparing this expression with the formula giving the synchronous speed of either motor alone, it is clear that the synchronous speed of the two motors connected in cascade is the same as the synchronous speed of a single motor wound for a number of poles equal to the sum of the poles in the first and in the second motors.

EXAMPLE 1.—Two similar motors are each wound with four poles, and the frequency of supply is 25 cycles per second. What is the speed of cascade synchronism?

SOLUTION.—In this case, $P = 4$, $P' = 4$, and $\sim = 25$. Substituting these values in the formula given in Art. 21,

$$N = \frac{120 \times 25}{4 + 4} = 375 \text{ R.P.M. Ans.}$$

EXAMPLE 2.—Two three-phase motors are coupled in cascade, the first motor being wound with four poles and the second motor with six poles. The frequency of supply is 15 cycles per second. What will be the synchronous speed of each motor separately, and at what speed will the motors run when connected in cascade?

SOLUTION.—The synchronous speed of the first motor alone is $\frac{120 \times 15}{4} = 450 \text{ R.P.M. Ans.}$ The synchronous speed of the second motor alone is $\frac{120 \times 15}{6} = 300 \text{ R.P.M. Ans.}$ The cascade synchronous speed of the two motors is $\frac{120 \times 15}{4 + 6} = 180 \text{ R.P.M. Ans.}$

23. Cascade Arrangements for Three Speeds.—If the primary and secondary motors are wound for different numbers of poles, three economical running speeds can be obtained without rheostatic losses. In the preceding example, if the primary motor is operated alone, a synchronous speed of 450 revolutions per minute is obtained. With the secondary motor running alone, the synchronous speed is 300 revolutions per minute, and with the primary and secondary motors in cascade, a speed of 180 revolutions per minute is obtained.

24. Regeneration With Two-Speed Equipment.—A pair of motors connected in cascade behave in precisely the same way as a single motor whose synchronous speed is the same as the cascade synchronous speed of the pair. A pair of motors in cascade will act as a motor at all speeds below cascade synchronism, and as a generator at speeds above cascade synchronism. If a train is hauled by a motor coach fitted with two pairs of three-phase motors, each wound for four poles, that is, two primary and two secondary motors, and the frequency of the supply is 25 cycles per second, there will be two economical

running speeds, namely, 750 revolutions per minute and 375 revolutions per minute, neglecting slip. When starting from rest and running up to full speed, the motors will be connected in cascade in pairs up to a speed of 375 revolutions.

25. Acceleration With Two-Speed Equipment.—When the motor coach is to be started from rest, the motors will be connected in cascade and resistance will be included in the rotor circuit of the secondary motor. As the speed increases, the resistance is reduced, and for the conditions outlined in the foregoing article a speed of nearly 375 revolutions per minute for the motors will be reached when the resistance is short-circuited. Further increase in speed is obtained by connecting the motors directly to the supply system having resistance in the secondary circuit of each, and gradually reducing this resistance until it is finally short-circuited and the speed is nearly 750 revolutions.

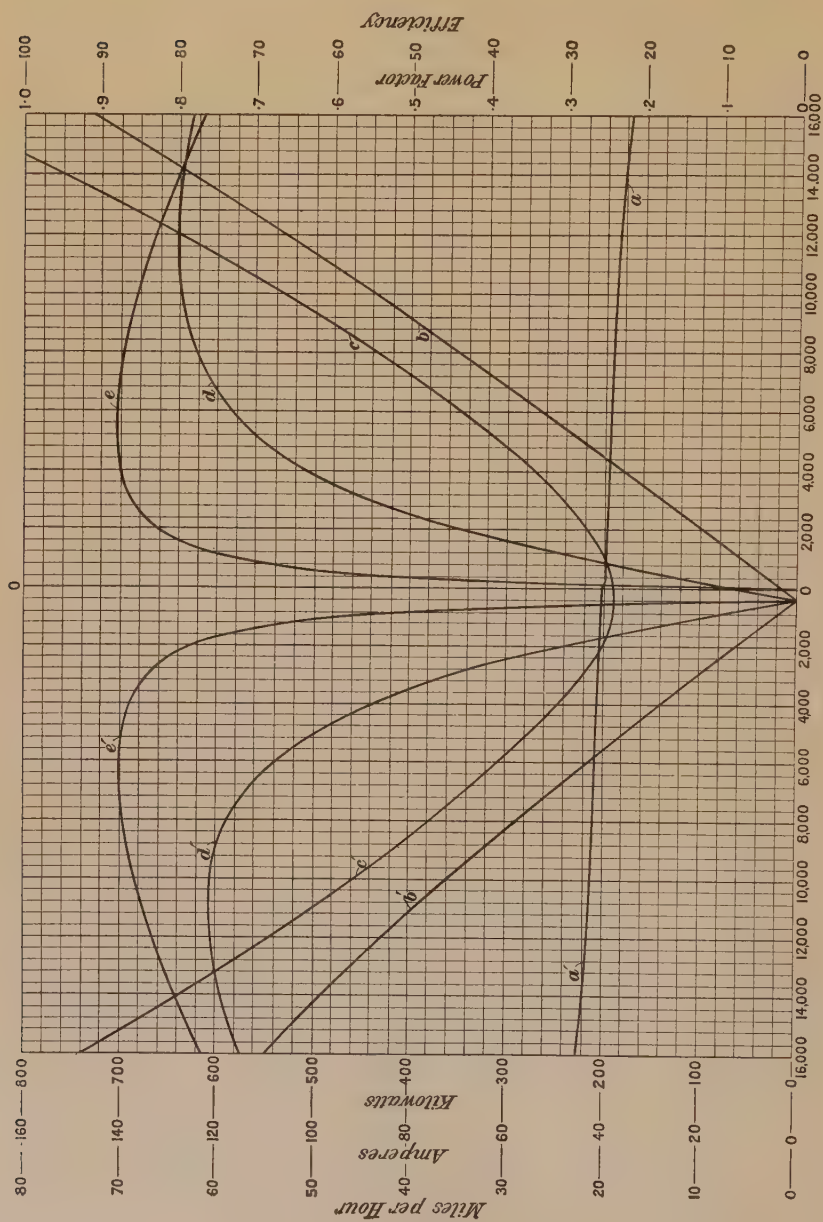
26. Retardation With Two-Speed Equipment.—In descending gradients the speed of the four-pole motors will rise slightly above 750 revolutions per minute, and will then hold the train in check by acting as generators. If it is desired to reduce the speed, resistance should be inserted in the rotor circuit of the secondary motor and the motors should be connected in cascade. As the speed is reduced owing to the regenerative action, the resistance should also be reduced. Below the speed of cascade synchronism the brakes on the train must be used to secure the desired retarding effect.

27. Acceleration With Three-Speed Equipment.—In order to illustrate the advantage of a three-speed equipment in accelerating a train, the action of a locomotive provided with two motors, one wound for eight poles and the other for twelve, will be considered. If the frequency is 15 cycles per second, the speed of the primary motor alone is $\frac{120 \times 15}{8} = 225$ revolutions per minute; the speed of the secondary motor is $\frac{120 \times 15}{12} = 150$ revolutions per minute; and the speed of the two when connected in cascade is $\frac{120 \times 15}{20} = 90$ revolutions per minute.

In starting from rest, the cascade connection is used and resistance is inserted in the rotor circuit of the secondary motor. After the speed has reached nearly 90 revolutions per minute, the resistance being cut out gradually, the secondary motor alone is connected to the supply mains and resistance is again inserted in the rotor circuit, this resistance being reduced as the speed increases. For speeds above 150 revolutions per minute, the primary motor is connected directly to the mains, resistance is included in the rotor circuit, and the secondary motor is disconnected. It may not be necessary to include resistance in the rotor circuit of the primary motor except when extra torque is required at a speed somewhat below the normal speed. The maximum speed of nearly 225 revolutions per minute is reached when the rotor of the primary motor is short-circuited.

28. Retardation With Three-Speed Equipment.—When it is necessary to reduce the speed of a train which is equipped with induction motors arranged for three speeds, the secondary motor is connected to the mains and the primary motor is cut out. Resistance is gradually cut out of the rotor circuit of the secondary motor until it is running at practically synchronous speed. The next step in the speed reduction is accomplished by connecting the two motors in cascade, with resistance in the circuit of the rotor of the secondary motor. This resistance is gradually reduced until the cascade synchronous speed is reached. Speeds below the cascade synchronous speed cannot be obtained by using the motors, as they cannot act as generators at low speeds.

29. Characteristic Curves of Motors in Cascade.—The characteristic curves previously given in Fig. 2 for a single motor relate to one of the earlier types of compound three-phase motor used on the Valtellina Railway in Northern Italy. The characteristic curves for the same machine when the primary and secondary motors are connected in cascade are shown in Fig. 7. Each compound motor consists of two distinct motors built on the same shaft and in the same outer case. The primary motor has eight poles and is wound for a pressure of 3,000 volts at a frequency of 15 cycles per second; the secondary motor also has eight poles, but is wound for a pressure of about 300 volts



Draw-Bar Pull in Pounds

FIG. 7

The curves to the right of the ordinate 00 are those for the machine running cascade-connected as a motor, and those on the left of 00 show the performance of the machine when regenerating. The curves a and a' give the speed of the train, the motors in the first case driving it and in the second case being driven as generators by the train, the synchronous speed being 20 miles per hour. The curves b and b' show the input and output, in kilowatts, when motoring and regenerating, and the curves c and c' , d and d' , and e and e' show the current, power factor, and efficiency, respectively, under motoring and regenerating conditions.

30. Comparison of Curves.—The summary of a comparison of some of the points on the curves in Fig. 2 and in Fig. 7 is given in Table I. The maximum values of the power factor of

TABLE I
COMPARISON OF CHARACTERISTICS OF SINGLE
MOTOR WITH CHARACTERISTICS OF CASCADE-CONNECTED
MOTORS

Characteristic	Single Motor		Cascade Motors	
	Motoring	Regener- ating	Motoring	Regener- ating
Maximum power factor . . .	.934	.925	.80	.76
Maximum efficiency . . .	94.5	95.0	88.0	87.5
Speed, miles per hour . . .	38.5 to 40	40 to 42	17.4 to 20	20 to 22.7
Maximum kilowatts . . .	850	750	728	550

a single motor when motoring and regenerating are given in the table as .934 and .925, respectively, while, when the motors are in cascade, the maximum values are .80 and .76. The fall of power factor when in cascade is due to the fact that the lagging

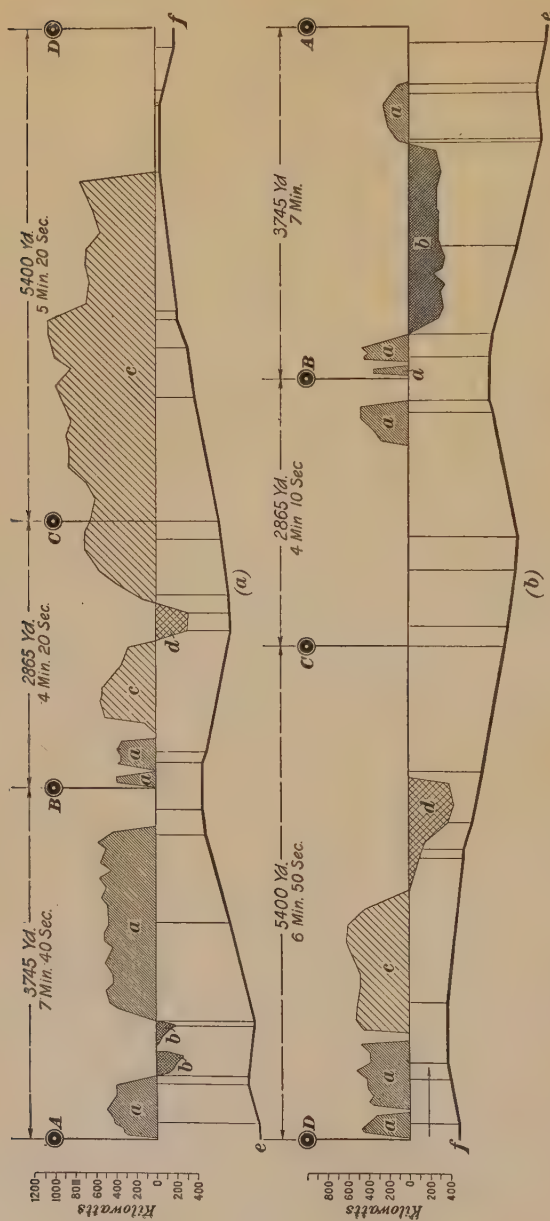


FIG. 8

current for magnetizing the secondary motor has to be supplied from the rotor of the primary motor. Thus, sufficient lagging current to magnetize both motors has to flow into the stator of the primary motor. It is necessary when motors are to be worked in cascade that each machine should have a high power factor when run separately, in order that the power factor when in cascade shall not be too low. The overload capacity of any induction motor depends on the maximum value of the power factor, so that the importance of making it as high as possible is at once evident.

31. Absorption and Regeneration of Energy.—The energy absorbed and regenerated by a train propelled by three-phase motors arranged for two-speed cascade control is represented graphically in Fig. 8. The train weighed 224 tons and was hauled by a locomotive weighing 62 tons, which was fitted with compound three-phase motors. Fig. 8 (*a*) gives the results when the train travelled from *A* to *D*, and Fig. 8 (*b*) when it travelled in the opposite direction. In the shaded areas, the horizontal line represents distance, the actual distances between stations and the time taken to traverse them being marked on the diagram. The vertical height of the curve above the base line represents kilowatts supplied to the locomotive, and the vertical distance below the line represents kilowatts regenerated. The areas *a*, closely shaded with thin lines, represent energy absorbed by the locomotive at half speed. The areas *b*, closely cross-hatched with fine lines, show the energy regenerated at half speed. The open-shaded areas *c* represent the energy taken at full speed, and the open cross-hatched areas *d* show the energy regenerated at full speed. The gradients of the line are shown by curve *e f*. In the run from *A* to *D*, the train stopped at station *B*, but ran through station *C*. The maximum value of the power absorbed was about 1,000 kilowatts, and that of the power regenerated about 400 kilowatts. The actual amount of energy regenerated during this run was, however, very small, because the line is mostly up-hill, as shown by curve *e f*. In the run from *D* to *A*, the amount of energy regenerated was much larger in comparison with that absorbed. It will be noticed

that the train coasted for quite a large part of the distance, the route being largely down-hill, as shown by curve $f e$, which is curve $e f$ reversed.

POLE-CHANGING SYSTEM OF SPEED CONTROL

32. Principle of Action.—The speed at which any induction motor rotates when supplied with current at a given frequency depends primarily on the number of poles for which the motor is wound. Therefore, if the number of poles on the motor can be changed, there will be an economical running speed corresponding to each number of poles. For example, a motor wound for four poles, and provided with an arrangement for doubling this number, would, on a circuit having a frequency of 15 cycles per second, give two synchronous speeds, namely, $\frac{120 \times 15}{4}$

$= 450$ revolutions per minute and $\frac{120 \times 15}{8} = 225$ revolutions per minute.

By employing suitable windings, motors could be arranged to give more than two numbers of poles, but in practice, under the conditions that obtain in traction work, it has only been found necessary to provide means for changing the number of poles in the ratio of 1 to 2.

33. Method of Changing Connections and Poles.—The diagrams in Figs. 9 and 10 show the method of changing the connections to the stator windings of an induction motor in order to change the number of poles. Each of the phase windings of the three-phase stator is split up into two parts, $a_1, a_2, b_1, b_2, c_1, c_2$, which are connected up to form a closed winding, as shown in Figs. 9 (a) and 10 (a). Each half of each phase winding includes the coils per phase of alternate poles. The junctions 1, 2, 3, 4, 5, and 6 of the windings are connected to the fingers of a barrel switch. The three-phase supply mains x, y, z are also connected to fingers on the barrel switch. The way in which the switch fingers are connected up by the contacts on the drum for the greatest number of poles, for example eight, is shown in Fig. 9 (a). At the instant when

current is flowing in along phases x and y , and out on phase z , the direction of current in the windings $a_1, a_2, b_1, b_2, c_1, c_2$ is as indicated by the arrows.

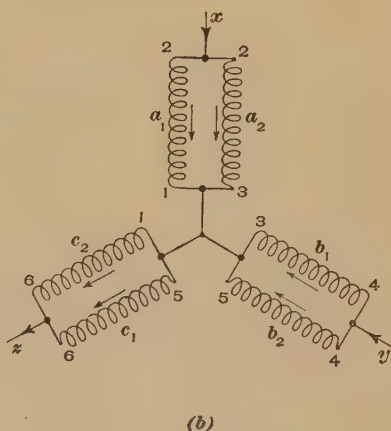
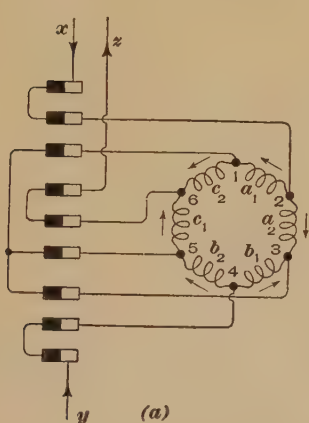


FIG. 9

34. The arrangement given by the connections outlined in the foregoing article can be found by tracing through the diagram in Fig. 9 (a), and is also shown in Fig. 9 (b). A star

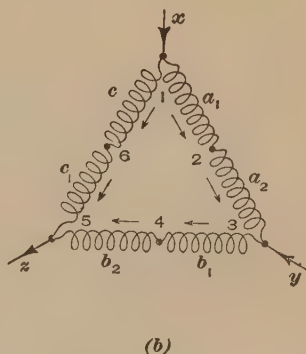
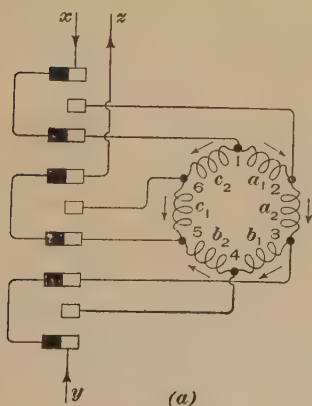


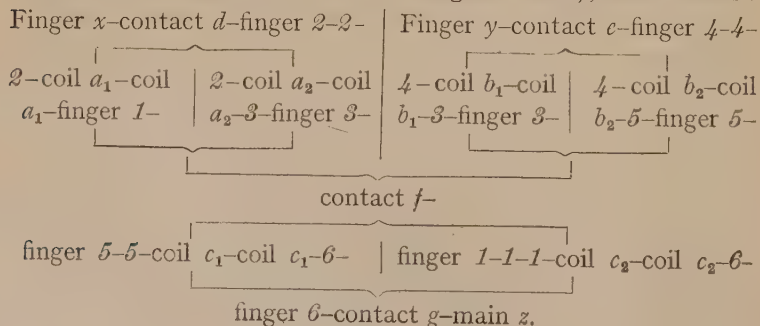
FIG. 10

connection is obtained, each arm of the star being composed of the two divisions of one phase, connected in parallel, the arrows showing the direction of current. In order to give the

connections for the minimum number of poles, for example four, the barrel of the switch is turned farther, and a second set of contacts connect up the switch fingers as shown in Fig. 10 (a), the equivalent winding obtained being given more simply in Fig. 10 (b), which is a delta connection, each arm of the delta consisting of the two divisions of one phase, in series. By comparing Figs. 9 and 10, it will be seen that the direction of current in the windings a_1 , b_1 , and c_1 is different in the two diagrams, while the current directions in windings a_2 , b_2 , and c_2 remain unaltered. The reversal of the direction of current through half the coils per phase in this case results in combining two poles into one and making the total number only half as great as before.

35. Winding Diagram.—A diagram of the windings of the stator of a three-phase induction motor arranged so that either eight or four poles may be obtained is shown in Fig. 11. The windings of each phase are shown in a distinctive colour, black, red, or blue, and the terminals are carried to the contact fingers of a barrel switch shown in the centre of the diagram. There are two slots per phase per pole for the eight-pole arrangement; the coils are indicated by a single line in order to simplify the diagram. The letters and numbers indicating the parts and terminals of the winding correspond to those used in Figs. 9 and 10.

36. The path of the current through the windings, assuming that contacts d , e , f , and g , Fig. 11, are in use and that current enters from the mains connected to fingers x and y , is as follows:



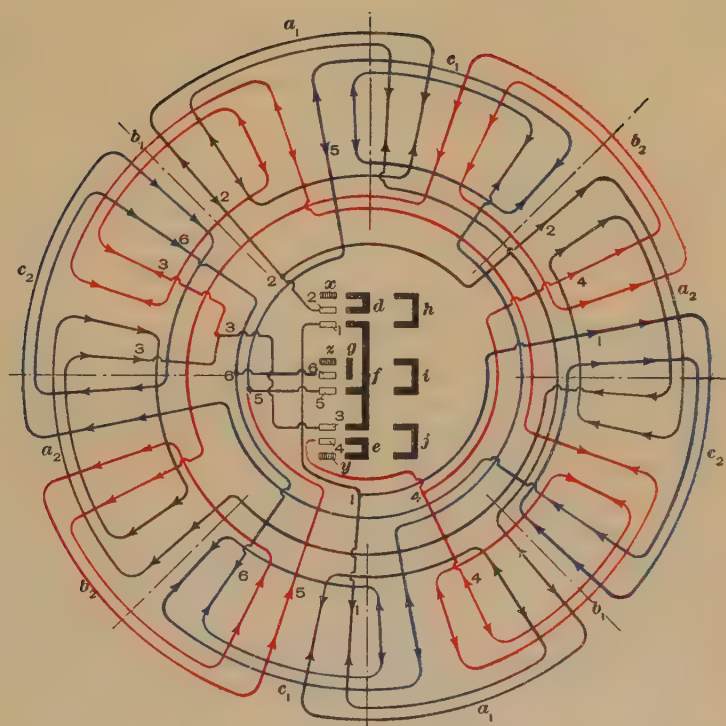
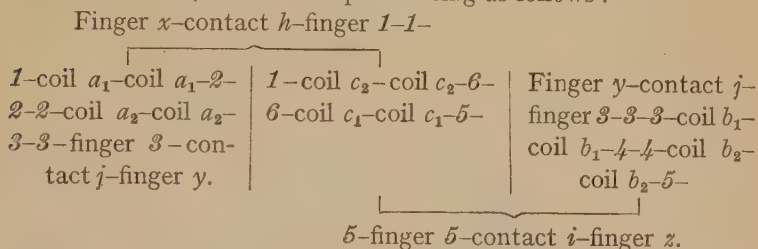


FIG. 11

The direction in which the current flows in the various conductors is indicated by the outer set of arrowheads.

37. In order to make connections to the windings, so that only four poles will be formed on the stator, the contacts h, i, j . Fig. 11, are brought into connection with the fingers of the switch. The direction of the current through the various conductors is indicated by the inner set of arrowheads. The windings are delta-connected, the current paths being as follows :



38. In order to avoid confusion in showing how the poles are formed, the directions of current in the conductors, taken from Fig. 11, are shown again in Fig. 12. The outer set of conductors are marked with arrowheads showing the current directions for the eight-pole arrangement. As all the conductors in one pole region must have current flowing in the same direction, one pole region must end and another begin where the direction of current in the conductors changes. It will be seen that the conductors in the outer ring are divided into eight groups, the current flowing in opposite directions in alternate groups, and thus producing alternate north and south poles N and S .

39. The inner set of conductors and arrowheads in Fig. 12 show the current directions for the four-pole arrangement. Spaced between the four actual pole regions marked N and S , there are regions marked A . The currents flowing in the conductors in these regions to a large extent neutralize one another magnetically, and also set up small local magnetic fields, which slightly reduce the torque which the motor is capable of giving and lower the power factor. The four main polar regions are, however, obtained as shown. If the pressure between the supply terminals is E volts, each of the sections $a_1, a_2, b_1, b_2, c_1, c_2$,

Fig. 11, will receive a pressure of $\frac{E}{\sqrt{3}} = .577 E$ volts when connected for eight poles. When connected for four poles, each section will receive $\frac{E}{2} = .5 E$ volts. As the maximum torque which the motor is capable of giving depends on the square of

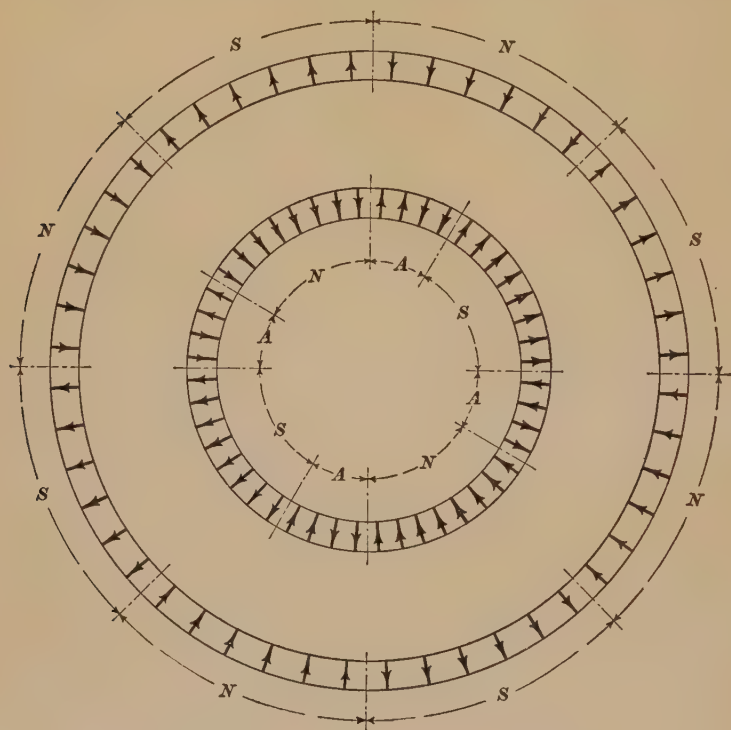


FIG. 12

the applied voltage, the maximum torque available is less than it would be with full voltage across the coils.

40. Rotor Connections.—At the same time that the number of poles on the stator is changed, the rotor windings must also be changed. This can be done by fitting the rotor slots with two separate three-phase windings, one for each number of poles,

and connecting each winding with a separate set of slip-rings. Then, when the barrel switch is moved over to alter the number of poles on the stator, the same movement raises the brushes from one set of slip-rings and lowers the other brushes on to the slip-rings of the second winding. If a squirrel-cage rotor is used, it will operate equally well with either number of poles on the stator, and the complication of slip-rings and brushes is avoided. For motors where three and four speeds are required, this is very important, as the number of slip-rings would be large. The use of squirrel-cage rotors for traction motors will be considered in detail later.

41. Compound Motors With Provision for Changing Number of Poles.—The pole-changing method of working has been developed beyond the stage already described by making use of compound three-phase motors. If one stator is wound for six and twelve poles, and the other for eight and sixteen poles, it is clear that there are four possible synchronous speeds. For example, with a frequency of 15 cycles per second, the speeds will be 300, 225, 150, and 112.5 revolutions per minute.

This development has been carried out by Brown, Boveri & Co. in their latest locomotives for the Simplon Tunnel Railway. The method of changing the poles on the stators is the same as that already described. A squirrel-cage rotor is used, the control of speed being effected by variation of the voltages applied to the stator windings and by using one or the other motor with the variation of the number of poles.

The elimination of external controlling resistances is a matter of considerable interest from the electrical as well as from the mechanical point of view. In railway work, the simplicity of construction and the avoidance of all rubbing contacts between brushes and slip-rings is often of greater importance than 1 or 2 per cent. difference in efficiency, and by careful design the desired simplicity can be obtained without excessive sacrifice of efficiency.

42. Determination of Resistance for a Squirrel-Cage Rotor. The disadvantage of using squirrel-cage rotors for traction motors is that, if they are designed as is usual for ordinary

induction motors, they give a very small starting torque and take a very large lagging current. This is because the resistance of a squirrel-cage rotor is small compared with its inductance, so that the rotor current, when the frequency is high, as at starting, lags very much behind the E.M.F. driving it. If the resistance of the rotor is increased, the rotor current is somewhat reduced, but it is brought more nearly into phase with the E.M.F., and the torque increases. On further increasing the rotor resistance, a point is reached when the reduction of starting torque produced by the reduction of rotor current is greater than the improvement in torque produced by the smaller angle of lag. It is clear, therefore, that there is a certain resistance for every squirrel-cage rotor which enables the motor to give its maximum starting torque.

43. There is, however, another point to be considered. Increasing the resistance of the rotor increases the copper loss in the rotor, and therefore reduces the efficiency of the motor. In an ordinary motor with a squirrel-cage rotor, the rotor copper loss is usually somewhat less than the stator copper loss. For a traction motor a large starting torque is essential, and a balance must be struck between the increased starting torque

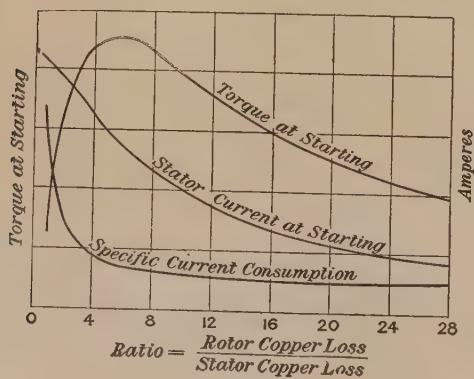


FIG. 13

and the reduced efficiency, and the ratio of the rotor copper loss to the stator copper loss must be made considerably greater than unity. The curves in Fig. 13 show how the torque at starting varies for different ratios of rotor copper loss to stator copper loss. The lowest curve shows the

specific current consumption, that is, the current required per 100 pound-feet of starting torque. The maximum torque is

obtained for the particular case taken, when the rotor copper loss is between 5 and 6 times the stator copper loss. This would, however, give too low an efficiency, and a sufficiently good starting torque is obtained when the ratio is reduced to a value of 3. The specific current consumption at this point is also fairly low.

44. Control of Motor With Squirrel-Cage Rotor. — As the resistance in a squirrel-cage rotor of an induction motor is invariable, the control of the torque and of the motor in general

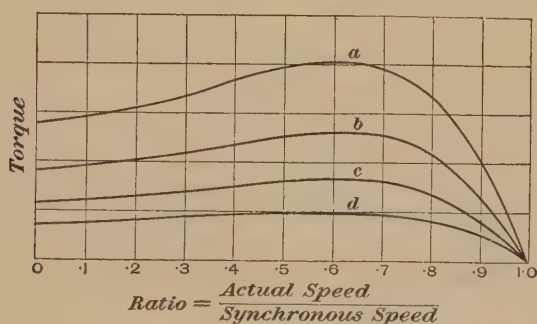


FIG. 14

must be effected by the only available means, namely, by varying the voltage applied to the stator windings. The windings

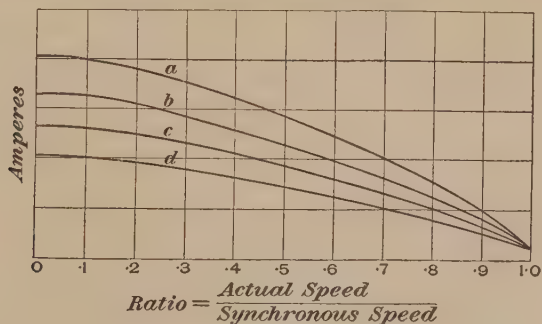


FIG. 15

receive current from suitably constructed transformers carried on the locomotive, arranged with a large number of tappings so that any desired voltage can be obtained. When starting up,

a low voltage is applied to the stator windings, and as the speed increases, the voltage is gradually raised to the full value. The variation of the torque corresponding to different voltages as the speed rises is shown in Fig. 14, curves *a*, *b*, *c*, *d* of torque against speed being given for the full voltage, and for values $\cdot 8$,

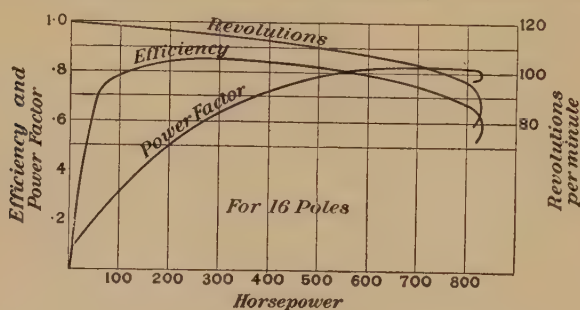


FIG. 16

$\cdot 65$, and $\cdot 5$ of the full voltage, respectively. In Fig. 15 the corresponding variations of the stator current, with speed for the same values of the terminal voltage, are shown by the curves *a*, *b*, *c*, and *d*. The current in each case is greatest at starting, and gradually decreases as the speed approaches the synchronous speed.

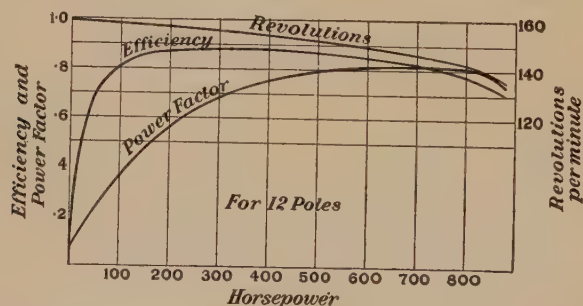


FIG. 17

45. Performance Curves for Compound Motor.—Curves showing the speed in revolutions per minute, efficiency, and power factor, of a compound three-phase induction motor when connected for sixteen, twelve, eight, and six poles, respectively, are given in Figs. 16, 17, 18, and 19. When the load is small, less

than 100 horsepower for the motor under consideration, the power factor is low, because the magnetizing current is a large proportion of the total current, especially for the arrangements of the winding giving large numbers of poles and low speeds. The shape of the efficiency curve is changed by changing the number of poles, but the effect is not the same in every case.

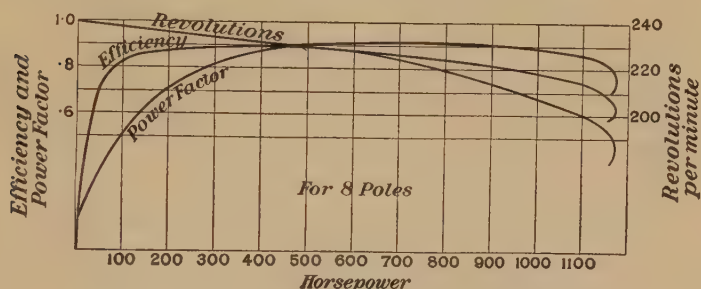


FIG. 18

It is possible to increase the power factor at small loads by reducing the pressure applied to the stator windings of the motor. The reduction in applied pressure causes a reduction in the overload capacity of the motor, but this is not serious under normal operating conditions. The performance curves

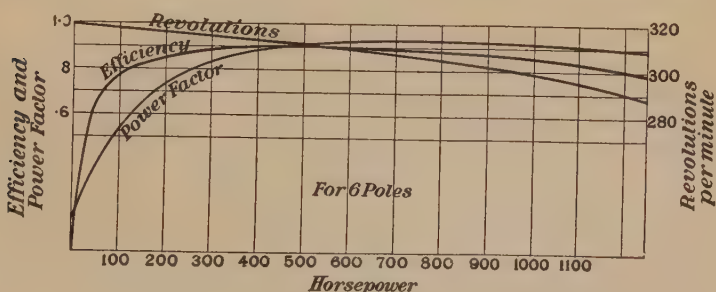


FIG. 19

in Figs. 20 and 21 show the influence of reducing the voltage on the efficiency and power factor at small loads. Fig. 20 refers to the motor working as a sixteen-pole machine, and Fig. 21 as a twelve-pole machine, the terminal voltage in both cases being reduced from 3,000 to 2,200 volts. As an example, compare

Figs. 17 and 21. In Fig. 17, the efficiency and power factor corresponding to 100 horsepower are $\cdot 81$ and $\cdot 35$, respectively, while, in Fig. 21, the corresponding values for the same output of 100 horsepower are $\cdot 87$ and $\cdot 57$. Thus, not only are the losses

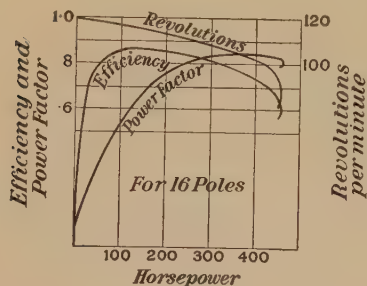


FIG. 20

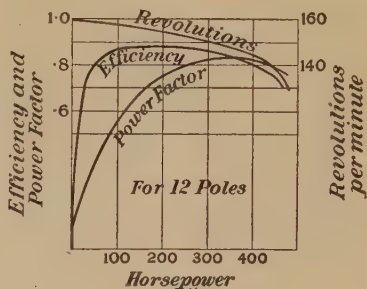


FIG. 21

in the motor reduced from 19 per cent. to 13 per cent., but the power factor is increased from $\cdot 35$ to $\cdot 57$, reducing the line current and therefore also the drop of voltage and the losses in the line.

EXAMPLES OF THREE-PHASE RAILWAYS

EQUIPMENT OF BURGDORF-THUN RAILWAY

46. The Burgdorf-Thun three-phase railway is a section of main line, 25 miles long, connecting the towns of Burgdorf and Thun, in Switzerland. It was equipped in 1899 by Brown, Boveri & Co., and is especially interesting as being the first main-line railway to be worked with three-phase alternating currents. The trolley-wire pressure is 750 volts, and the frequency 40 cycles per second. Current is supplied by the generators at a pressure of 4,000 volts, and the pressure is stepped up to 16,000 volts for the long-distance transmission system, and at various substations along the line is stepped down to 750 volts. There are two trolley wires, the rails forming the third conductor. The passenger trains consist of motor coaches and trailers, and run at a speed of $22\frac{1}{2}$ miles per hour. The luggage trains normally run at $11\frac{1}{4}$ miles per hour, and are

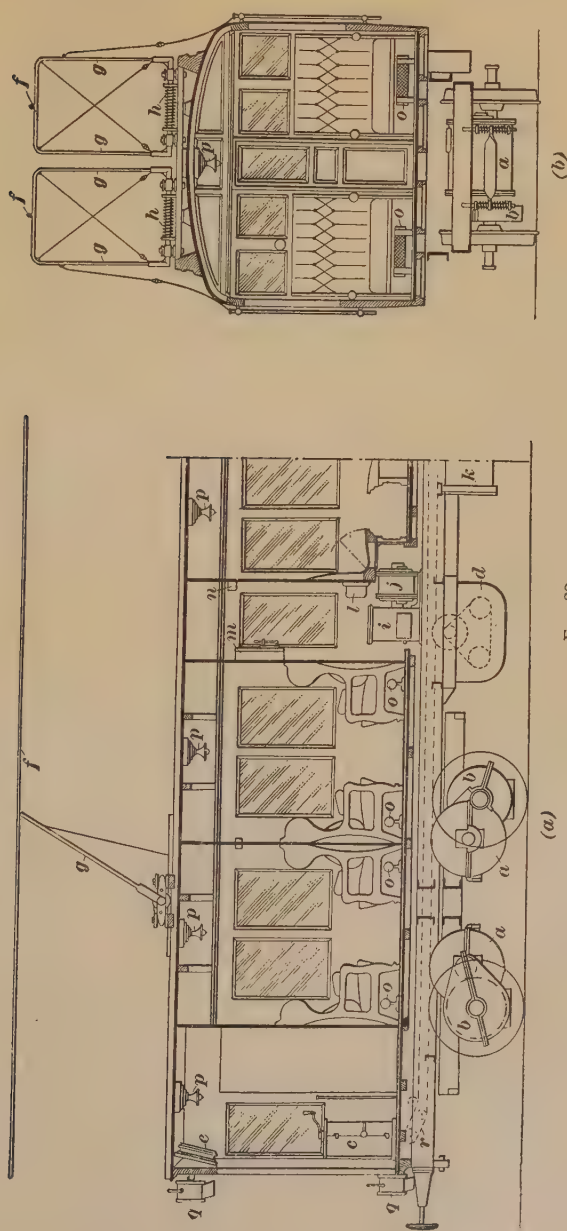


FIG. 22

hauled by locomotives. Two sets of gear-wheels on the locomotive enable the speed to be increased to $22\frac{1}{2}$ miles an hour when necessary.

47. Equipment of Motor Coaches.—Each motor coach on the Burgdorf-Thun Railway is fitted with four eight-pole 64-horse-power motors, each weighing 3,000 pounds, and having a synchronous speed of 600 revolutions per minute. Each motor is geared to one of the driving axles in the ordinary way through a forged-steel pinion and cast-steel wheel, the gear ratio being 3 to 1. The motors are suspended on springs, the suspension used being much the same as the nose suspension of a tramcar motor.

All four motors have their stator windings connected in parallel, and are started by means of rotor resistances. Fig. 22 shows the arrangement of the interior of a motor coach, view (*a*) being a longitudinal section through half a coach, and view (*b*) a transverse section. The details of the method of attaching the car body to the trucks are not given. The motors *a* are geared to the axle through a steel pinion and wheel enclosed in the casing *b*. The controller *c* is placed in a compartment at the end of the coach, and is mechanically coupled to the controller at the other end by means of gear-wheels and a chain *r*, so that the controller drums always occupy corresponding positions. The controlling resistance *d* is hung from the underframe of the coach. The current supplied is measured by the ammeter *e*, which is placed in such a position as to be easily read by the driver. Two trolley wires *f* are used, and the current collectors *g*, which are of the bow type, are pressed upwards against the wires by the springs *h*.

48. The air compressor *i*, Fig. 22, is used for operating the pneumatic brakes, and is driven by the motor *j*, which in turn is supplied with current at a pressure of 100 volts from the transformer *k*. The air pressure is kept at the desired value by means of the automatic switch *l*, which starts the compressor motor when the air pressure reaches a given minimum and stops it when the pressure rises to a given maximum. A small switchboard *m* is provided, on which the switches for the lighting and heating

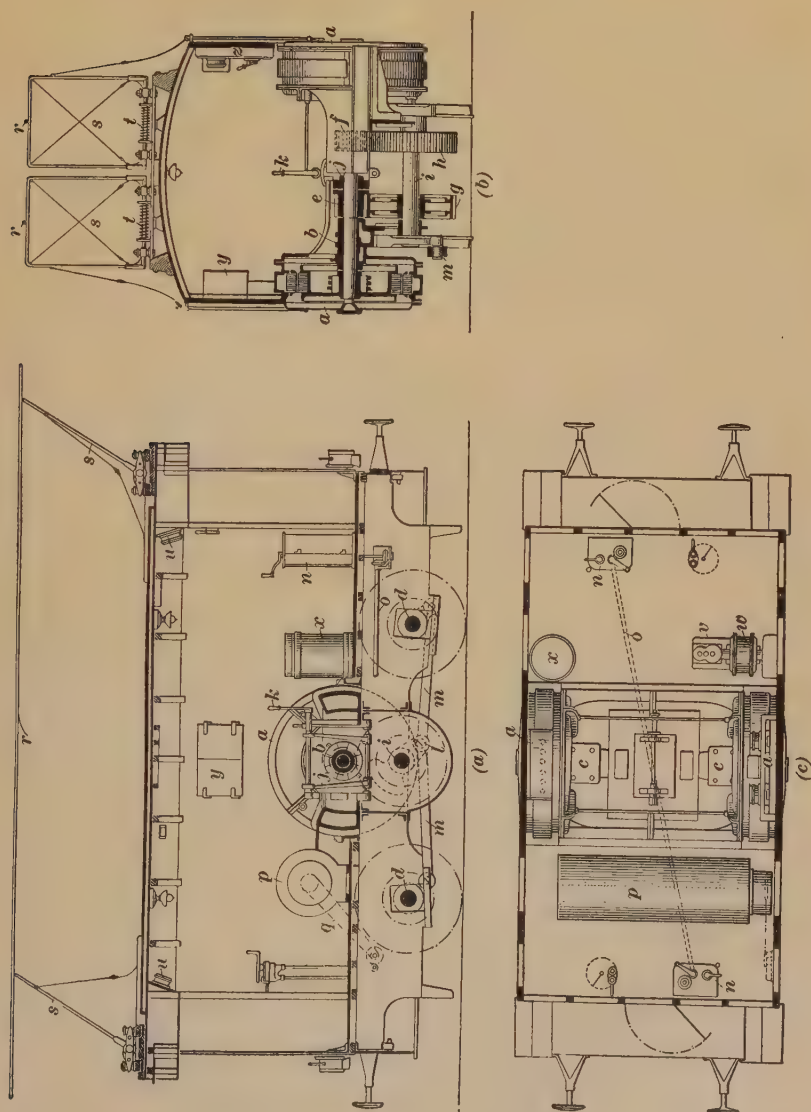


FIG. 23

circuits and the circuit-breakers for the compressor motor are placed. A lightning arrester is installed at *n*, in order that any static charges on the trolley wires may find an easy path to earth. The electric heaters *o* for warming the coach are situated beneath the seats, and the illumination is provided by lamps *p* fixed to the under side of the roof. Two head lights *q*, one at the top and one at the bottom of the coach body, are provided at each end. The coaches are fitted with pneumatic brakes of the Westinghouse type, and also with hand-brakes. Both these brakes are required only for stopping, as the speed of the train is controlled when descending inclines by the regenerative action of the motors.

49. Equipment of Locomotives.—The equipment of the locomotives in use on the Burgdorf-Thun Railway is illustrated in Fig. 23, view (*a*) being a longitudinal section, view (*b*) a transverse section, and view (*c*) a plan. Each locomotive is fitted with two sixteen-pole 150-horsepower motors *a*, having a synchronous speed of 300 revolutions per minute. They are mounted on the ends of a shaft *b*, which rotates in bearings *c* fastened on the truck frame midway between the two driving axles *d*. Two pinions *e* and *f* are mounted on the shaft *b*, and they gear with wheels *g* and *h* on an intermediate shaft *i*. These gear-wheels have two ratios, that of *e* and *g* being 1.88 to 1, and that of *f* and *h* being 3.72 to 1. Between the pinions *e* and *f* there is a clutch *j*, which can be moved along the shaft *b* by the handle *k* so as to engage with either of the pinions. In this way the speed of the locomotive may be 11 or 22 miles an hour while the motors run at constant speed. The connection between the shaft *i* and the driving wheels is made by means of crank *l* and coupling rods *m*.

50. The controllers *n*, Fig. 23, are coupled together by a shaft *o*, so that they cannot be in different positions. The rheostat for starting and controlling the motors is shown at *p*; it is operated by the chain *q* from either of the controllers. Current is collected from the two trolley wires *r* by the bow collectors *s*, which are pressed upwards by the springs *t*. When the driver is standing by either of the controllers, he has immediately in

front of him a 500-ampere ammeter *u*, from which he can tell the amount of current taken by the motors.

The air compressor *v* is driven by a small three-phase motor *w*, capable of giving 4 horsepower. A pressure of 100 volts, which is required by the compressor motor, is given by the step-down transformer *x*, this transformer also supplying current for light and heat. The fuses for the various circuits are contained in the sheet-steel box *y*, and on the opposite side of the driver's cab there is a switchboard *z*, on which are the instruments and switches for the lighting, heating, and compressor-motor circuits.

WIRING DIAGRAM FOR LOCOMOTIVE ON BURGDORF-THUN RAILWAY

51. Stator Circuit of Main Motors.—Fig. 24 shows the scheme of connections for the locomotive illustrated in Fig. 23. There are three separate circuits from the supply conductors to the various parts of the apparatus, one for each phase, but as they are all symmetrical, it will be sufficient to trace out one phase. Thus, in Fig. 24, the three supply conductors are the two trolley wires *a* and *a'* and the track rails *a''*, but the circuit from *a* only will be traced. Current is collected from *a* by the bow collectors *b*, and passes by way of bus-line *c* and the two ammeters *d*, *d'* to the controllers at *e*, *e'*. The two controllers are mechanically connected by a shaft and bevel gearing, so that when the driver actuates one of them the drum of the other moves in unison. When the proper movement has been made, the current of the phase under consideration leaves the controllers at *f*, *f'* and flows to the point *g*, part passing through fuse *h* to the terminal *i* of the stator of motor *j*, and part passing through fuse *h'* to the corresponding terminal *i'* of the stator of motor *j'*. The return circuit from the motor windings is to either conductor *a'* or *a''*.

52. Rotor Circuit.—The rotor circuit of the motors is entirely separate from the stator circuit. The slip-rings *k*, *k'*, Fig. 24, of the two motors *j* and *j'* are connected in parallel at *l* and to the resistances *m*, which can be gradually cut into or out of circuit by means of the movable contact-piece *n*. The movable

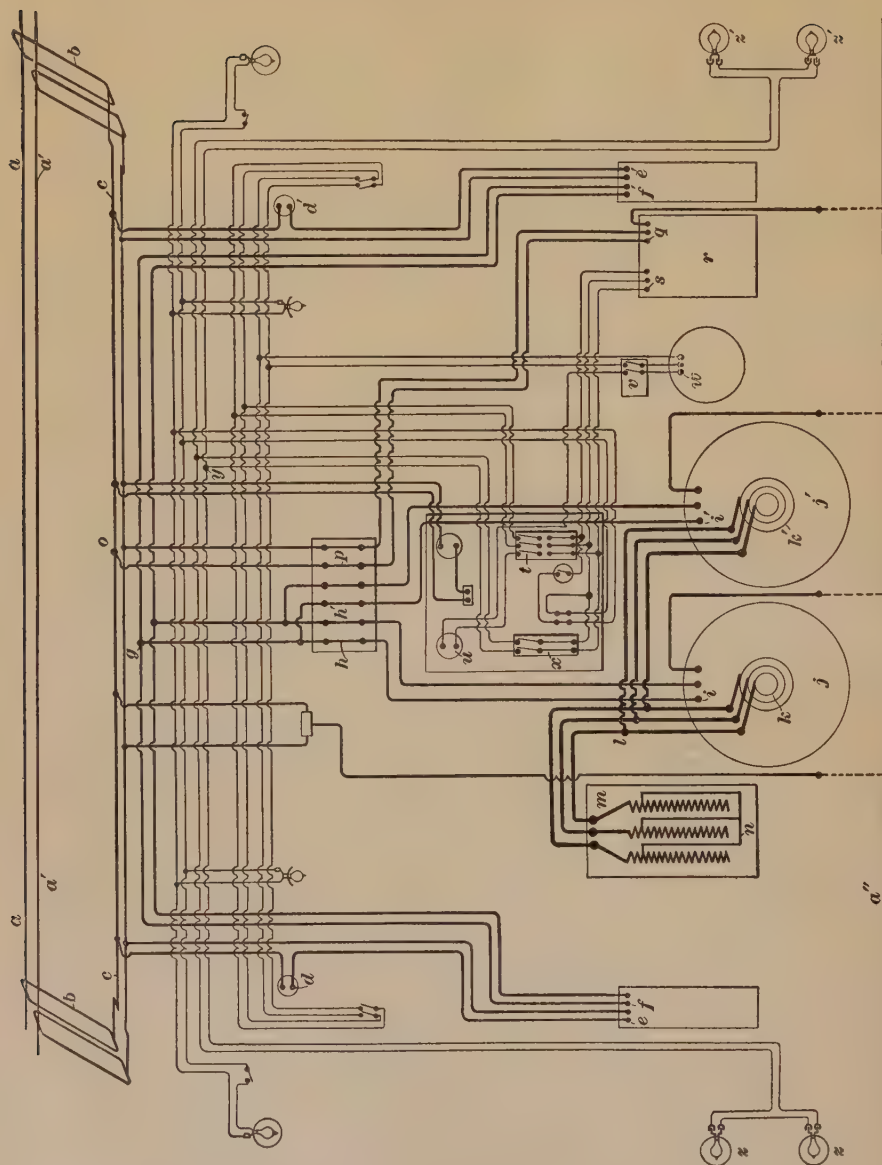


FIG. 24

part *n* of this rheostat is operated from the controller drum, so that when the driver rotates the drum he cuts resistance into or out of the rotor circuit.

53. Compressor-Motor Circuit.—The current for one phase of the compressor-motor circuit is taken from supply conductor *a*, through collector *b*, point *o* on the bus-line *c*, fuse *p* to primary terminal *q* of the step-down transformer *r*. From the secondary terminal *s* of the transformer the circuit is through one pole of the fuse and switch *t*, ammeter *u*, automatic switch *v* to terminal *w* of the compressor motor.

54. Head-Light Circuit.—The head lights are supplied from one phase of the step-down transformer *r*. Starting from the terminal *s*, the circuit is through one pole of the switch *x* and the low-tension bus-line *y* to the head lamps *z* or *z'*, the return path being similar to the one traced. The other lighting circuits of the locomotive are similarly connected to another phase on the low-tension side of the transformer *r*.

EQUIPMENT OF MOTOR COACHES FOR VALTELLINA RAILWAY

55. The Valtellina Railway is a section of main line about 67 miles long, situated near Lake Como, in North Italy. It was equipped on the three-phase system in 1900 by Ganz & Co., of Budapest. Power is generated at a hydro-electric station at 20,000 volts and is transmitted to substations along the line, where it is transformed down to 3,000 volts for supply to the conductors. There are two trolley wires, the track rails being used for the third conductor. Both motor coaches and locomotives are used on the system, the speed for passenger traffic being 42 miles per hour, and for freight service 21 miles per hour. This railway is interesting as being the first on which the principle of regeneration, or recuperation, was carried out fully, for it is not only made use of when the trains are descending grades, but is also used to return energy to the line when reducing the speed of the trains preparatory to stopping at stations.

56. General Arrangement of Motor Coaches.—Elevation and plan views, partly in section, are shown in Fig. 25 (*a*) and (*b*) of one of the motor coaches used on the Valtellina Railway. Current is taken from the trolley wires by one of the bow collectors *a*, and passes to a bus-line connected to the distribution boxes *b*. It then passes through the combined main and reversing switches *c*, which are operated by compressed air, and to the stators of the primary motors, one of which is shown at *d*. The motors are of the gearless type, the rotors being mounted on sleeves through which the wheel axles pass. Each pair of wheels is driven from its rotor through a link motion similar to that shown at *e*. This method of coupling enables the wheel axles to move relatively to the motors, and allows the motors to be spring-suspended. Every coach is furnished with four motors, two of which are wound for 3,000 volts and two for 300 volts. From starting, up to half speed, each high-tension motor is connected in cascade with a low-tension motor; from half speed to full speed the high-tension motors only are in circuit.

57. A controller *f*, Fig. 25, is situated at each end of each motor coach, and the rheostats *g*, by means of which the resistance in the rotor circuit is diminished or increased according to whether the motors are being started or stopped, are placed under the floor. These rheostats are of the liquid type, and have fixed electrodes, round which the liquid is forced by compressed air. The air compressor is shown at *h*, and is driven by the small three-phase motor *i*, which is supplied with current at 100 volts by an 8-kilowatt step-down transformer. This transformer also supplies the lighting and heating circuits. The compressor *h* forces air into the reservoir *j*, from which is taken the supply of compressed air for operating the main switches, trolley-raising device, liquid resistances for the rotor circuits, and brakes. The pressure of the air in the reservoir is kept constant by means of the automatic device *k*, which disconnects or connects the motor *i* as the pressure exceeds or falls below certain limits. The cylinder of the Westinghouse brake is shown at *l*, and *m* is a hand-brake, which can be used when required. A small hand pump is provided at *n* by the use of which the

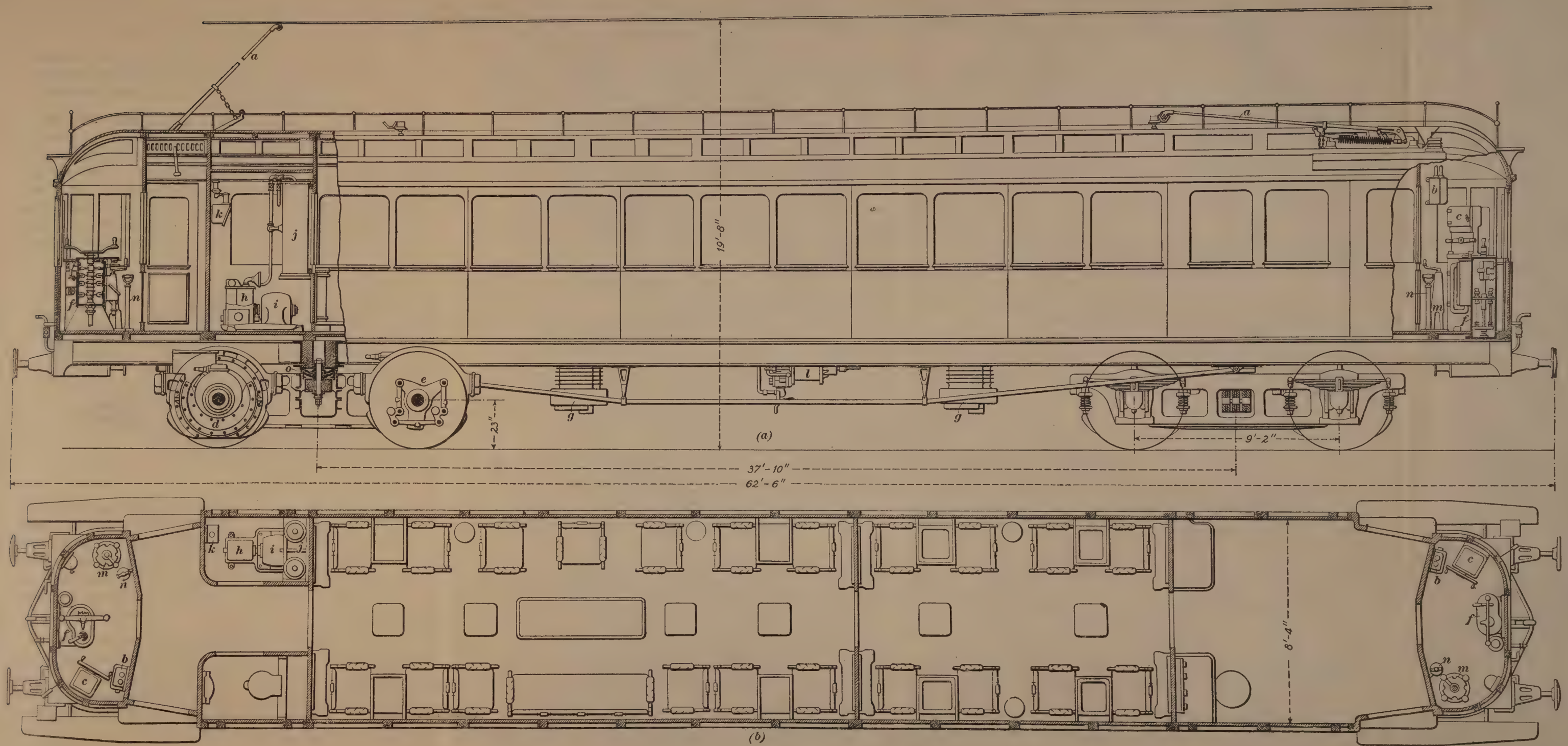


FIG. 25

collector bow can be raised when there is no pressure in the air reservoir. The arrangement by which the car body is attached to the bogie, so that the bogie is free to turn, is shown at *o*.

58. Motor Bogie.—The general construction of a bogie for a motor coach on the Valtellina Railway is shown in Fig. 26. The motors *a* and *a'* are fastened to the bogie frame by bolts, six of which are shown at end *b*. The rotor is, as previously mentioned, mounted on a hollow shaft, through which the wheel axles pass. The wheel axles are extended beyond the wheel, and run in axle boxes *c*, from which the bogie frame is supported through the laminated springs *d* and the spiral springs *e*. This

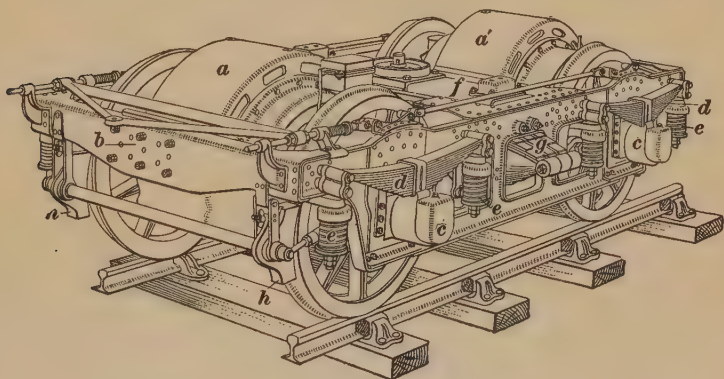


FIG. 26

method of supporting the bogie allows of relative motion between the motors and the wheels. The bolster on which the coach body is carried is shown at *f*, and is supported on the powerful laminated springs *g*, so that between the car body and the axles there are three sets of springs. Two of the brake blocks are shown at *h*. Each bogie carries one high-tension and one low-tension motor.

59. Flexible Coupling Between Rotor and Wheels.—The flexible coupling between the rotor and the track wheels is shown in Fig. 27. The hollow shaft, or sleeve, on which the rotor of the motor *a* is mounted is fitted at each end into a bracket *b* having three arms. Two of the arms of the bracket are pivoted to two

links d , d , the other ends of which are connected to two small bell-crank levers e . These bell-cranks are pivoted to two spokes f of the track wheel, and the free ends of the cranks are connected by the link g . When the rotor revolves it carries the three-armed bracket b with it, and this in turn transmits the rotative motion

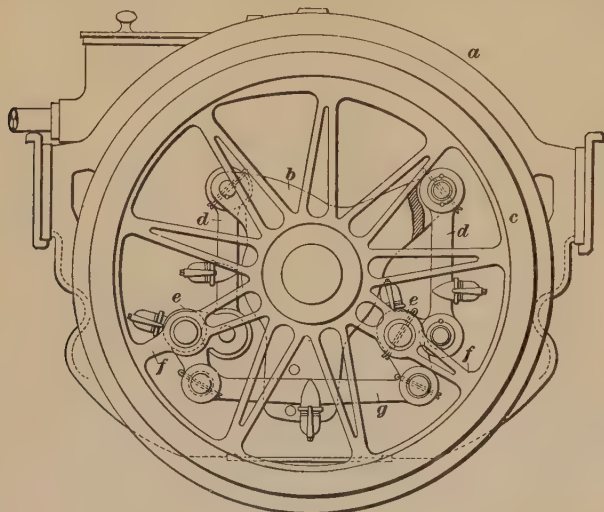


FIG. 27

to the track wheel through the links d and g and the bell-cranks e . If the rotor is not quite concentric with the axle, the links set themselves to suit, and the coupling allows the wheels to follow all the irregularities of the track, while the motors, as they are spring-borne, are carried smoothly.

60. Bow Collector.—Current is collected from the trolley wires by means of the bow collector shown in Fig. 28 (a), (b), and (c). View (a) is a side elevation, view (b) a front elevation, and view (c) a plan of the collector. Current is taken from the supply conductors by two copper cylinders, one of which is shown at a . The two cylinders are insulated from each other by a wooden roller b , and are supported in bearings at each end carried by a framework c of iron tubes. Carbon brushes are used to collect the current from the copper cylinders. The brushes are insulated from the frame c , and are connected

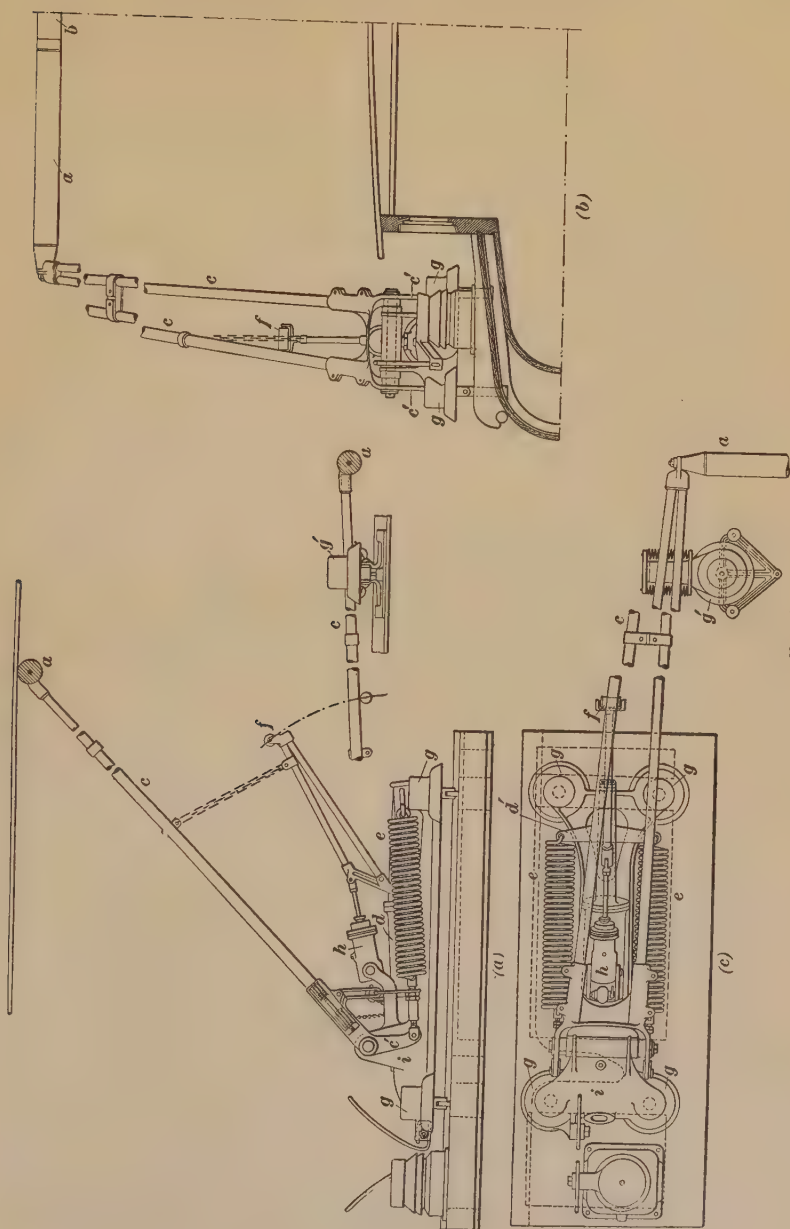


FIG. 28

to insulated cables supported on the frame. The air cylinder *d* is fitted with a piston and piston rod, the latter being connected to the crosshead *d'*, which is fastened to the two tension springs *e*. The tension springs are also attached to the lever arm *c'* of the collector frame. When compressed air is admitted into the cylinder *d*, the piston is forced to the right, thus putting the springs *e* in tension and raising the collector frame. If the air in cylinder *d* is released, the weight of the frame will cause it to force the piston to the left and the collector will be lowered. It will drop quickly until the frame *c* strikes the buffer *f*, which will descend only gradually on account of the action of the dashpot *h*. The base *i* of the collector is mounted on insulators *g* carried on the roof of the coach. When the collector is down, it rests on a coil spring carried on special insulators *g'*.

61. Main and Reversing Switch, and Controller.—The combined main and reversing switch consists of a disc of insulating material, to the edge of which six copper pins are attached. When the switch is closed, these pins fit into sockets provided with metallic contact-pieces carried on a similar disc placed above the first. When the lower disc is raised, contact is made between the pins and the socket contacts, and when the disc is lowered, the circuit is broken, the rarefaction of air in the sockets extinguishing the arcs. This switch may be operated by means of a hand lever or by compressed air. As will be seen from the diagram of connections given in Fig. 30, the pins are joined in pairs, so that by rotating the disc through 60° the connections of two of the stator terminals to the overhead lines are interchanged, and therefore the direction of rotation of the motors is reversed.

The only places at which the high-tension wires are accessible are in the distribution box and the main switch. The cases of these parts of the apparatus are locked, and the key is placed in the trolley-raising apparatus. It can only be removed when the trolleys are lowered, that is, when the overhead wires are not connected, and the trolley cannot be raised until the key is in its place; the key, also, cannot be removed unless the cases are locked, so that there is little liability of danger due to the

cases being left open when the trolleys are making contact with the overhead wires.

The controllers present no very novel features ; no circuits are broken at the controller contacts, and therefore no provision need be made for dealing with arcs. The controllers are provided with contacts for making connection to the resistances, and for connecting the high-tension motors singly, or in cascade, with the low-tension motors ; in addition, each controller has a handle which controls the valve supplying compressed air for the purpose of operating the main switch. This switch cannot be operated until the controller handle is in one of the running positions, nor can the controller handle be turned to its off-position unless the handle operating the main switch has first been turned to the off-position, so that the main switch is open.

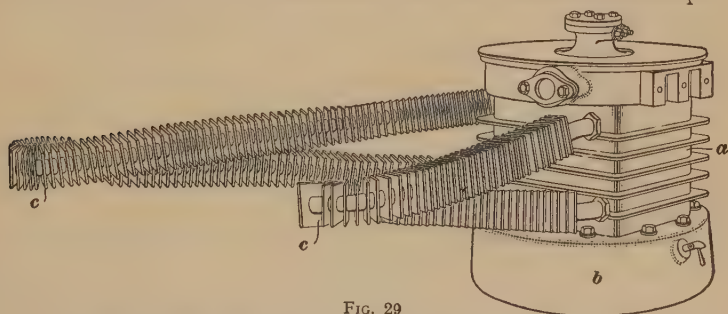


FIG. 29

62. Liquid Rheostat.—The resistance in the circuit of the rotor of each motor is varied by means of a liquid rheostat, a view of which is given in Fig. 29. The rheostat consists of a cast-iron receptacle *a*, in which three groups of plates of unequal length are contained, these three groups being joined to three terminals on the controller. An alkaline solution, which is contained in the base *b* of the rheostat, is forced into the upper part of the receptacle, and as soon as the liquid makes contact with the plates the rotor circuits of the motors are completed and the motors develop a turning effort. As the liquid rises the resistance decreases, and when it has reached its maximum height, the resistance is automatically short-circuited. In order to cool the liquid the case *a* is ribbed, and is furnished with heavily ribbed circulating pipes *c* offering a large radiating surface.

WIRING DIAGRAM FOR MOTOR COACH ON VALTELLINA RAILWAY

63. Main Motor Circuits.—A diagram of the connections of part of the electrical apparatus including one pair of motors only is given in Fig. 30, the connections for the second pair of motors and the remaining part of the apparatus being exactly similar. As the three phases of the three-phase circuit are symmetrical as far as the controller is concerned, it will be sufficient to trace through the connections for one phase, the return circuit in every case being through the other phases. Current is supplied by the two trolley wires a, a' and the rails a'' . Starting from trolley wire a , current passes down the collector b , through the choking coil c , and into the bus-line d . It then passes through the main fuse e and, when the main switch A is closed, from contact f to contact g . From contact g , part of the current flows by way of wire h to one stator terminal i of the high-tension motor B , and part flows along the wire h' to the high-tension motor at the other end of the coach, which is not shown.

64. For cascade working, the rotor of motor B , Fig. 30, is connected to the stator of the low-tension motor C , the circuit for one phase being from terminal j on motor B , through contacts k and l on the controller D , and along wire m to stator terminal n of motor C . The rotor of motor C is connected to the liquid resistance E , the current in one phase starting from terminal o and passing by way of the contacts p and q on the controller to terminal r on the resistance E . When the liquid resistance is reduced to its lowest value, the rotor connections are short-circuited by a special switch s .

In order to run the coach at full speed, only the high-tension motors are used, and their rotors are connected directly to the liquid resistances. This is effected by turning the controller handle into the second position, so that the other pairs of contacts in the controller, such as k and k' , Fig. 30, are connected together, thus putting terminal j of motor B in connection with one of the terminals of the resistance E .

65. Transformer and Lightning-Arrester Circuits.—The small step-down transformer for supplying the compressor motor,

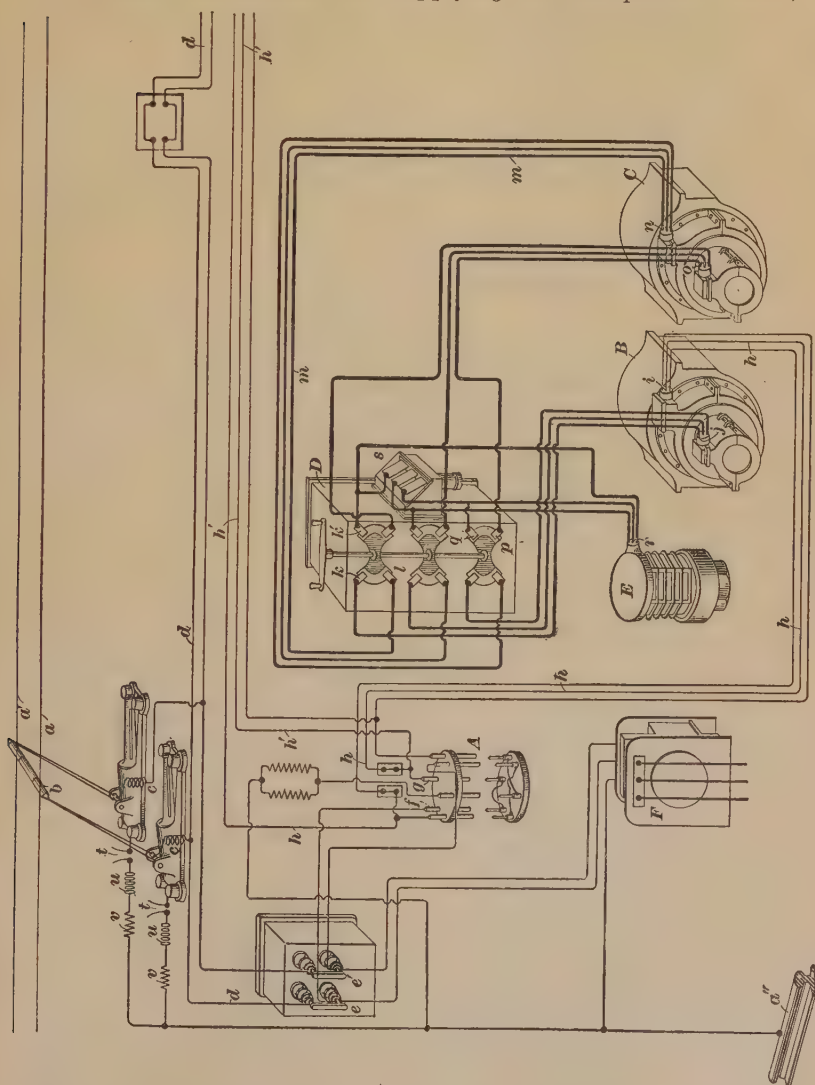


FIG. 30

heating, and lighting circuits is shown at *F* in Fig. 30. Two of its primary terminals are connected through the fuses *e* and *e'*

to the bus-lines, and thence to the trolley wires a and a' , and the remaining primary terminal is connected to the rails a'' .

There are two kinds of lightning arresters fitted to the car, namely, the horn type shown at t near the current collectors, and the Wurtz non-arcing metal type u in series with the horn type. Non-inductive resistances v are placed between the lightning arresters and earth to limit the rush of current which follows a lightning discharge. The choking coils c in the main circuit are for the purpose of preventing the static discharge from passing through the apparatus on the car.

TWO-SPEED LOCOMOTIVE FOR VALTELLINA RAILWAY

66. General Arrangement of Locomotive. — The two-speed locomotives for the Valtellina Railway are provided with two compound three-phase motors, which are coupled to the driving wheels by means of cranks and coupling rods. The general arrangement of the apparatus on the locomotive is shown in Fig. 31. The shafts of the rotors are fitted with cranks at each end, these cranks being placed at right angles to each other as on an ordinary steam locomotive. The cranks are provided with balance weights b , and are coupled together by the driving bar c . The driving bar transmits motion to the crankpin e of the central driving wheel a through a bearing having slides f , which permit vertical movement of the crankpin journal d . This vertical movement is necessary because the motors are mounted on the locomotive frame, which is supported on springs. The outer driving wheels, which are also marked a , are driven by means of coupling rods g jointed to the main driving bar c .

67. The outline of the motors is shown dotted at h , Fig. 31, and the controller is at i . The liquid rheostats j are placed at the front and back of the locomotive, and the small step-down transformer k at the extreme end. The compressor l supplies air to reservoirs m on the roof of the locomotive. The main high-tension switches are shown at n , and the low-tension switch at o , the electro-pneumatic relays being indicated at p . The pony wheels q of the locomotive are arranged so that they can

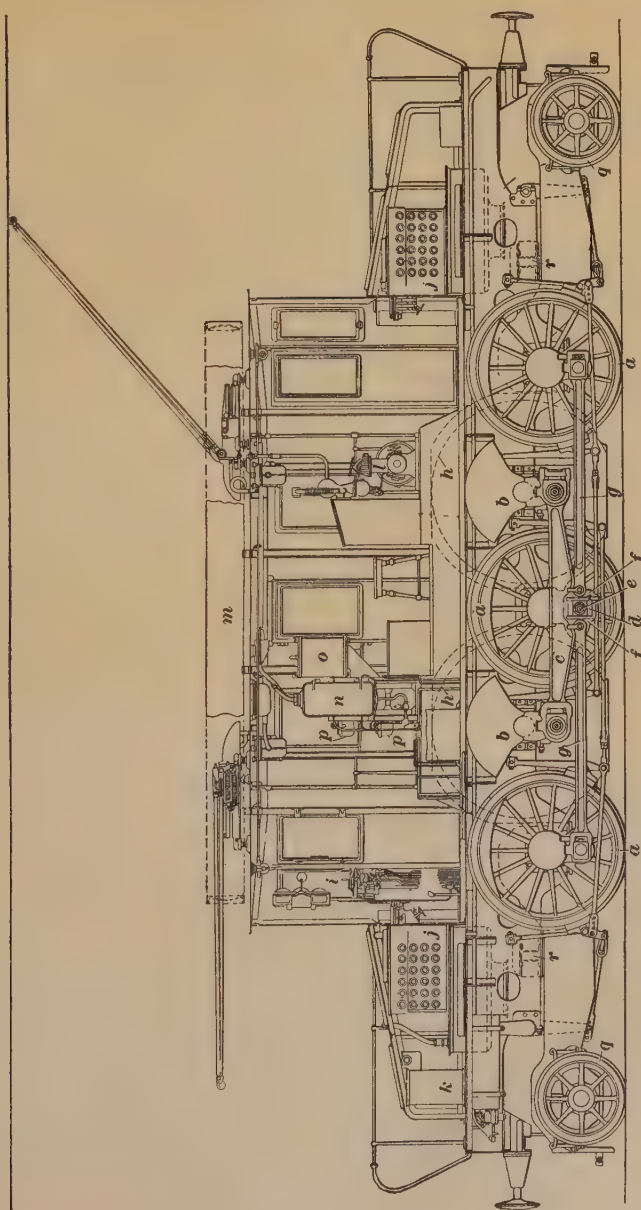


FIG. 31

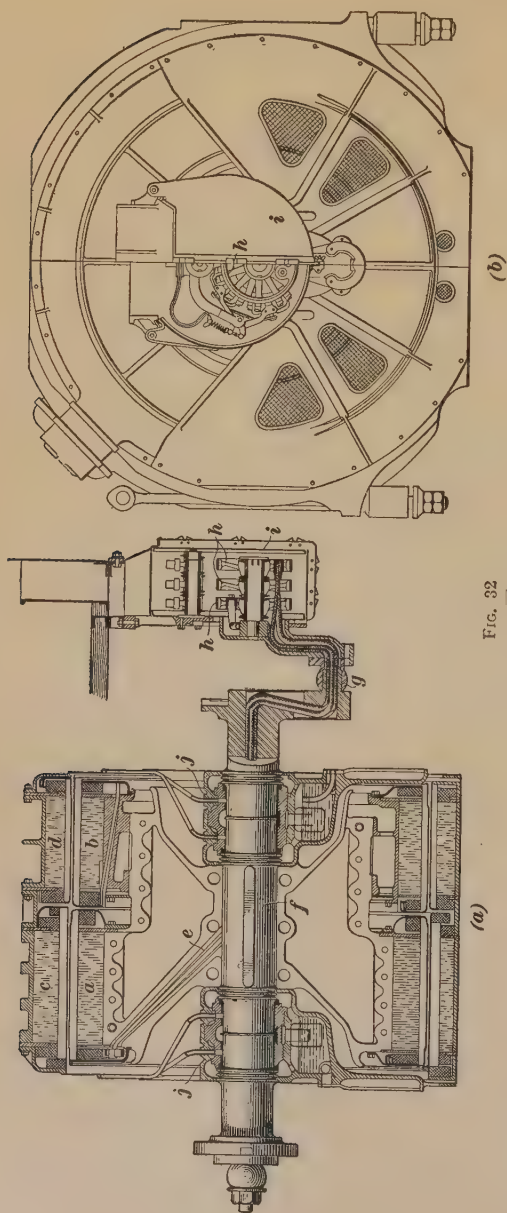


FIG. 32

turn slightly about a pivot *r*, thus allowing the locomotive to go round curves with ease.

68. Compound Motors of Locomotive.—A cross-sectional view of one of the three-phase compound motors used on the two-speed locomotive of the Valtellina Railway is shown in Fig. 32 (a), and an end view is given in Fig. 32 (b). Both the primary motor and the secondary motor are mounted in the same frame; the rotor *a*, view (a), of the primary motor is longer than the rotor *b* of the secondary motor. The slots in the primary stator *c* are deeper than those in the secondary stator *d*, as the windings of the primary motor must be insulated more carefully than those of the secondary.

69. The stator winding of the primary motor, Fig. 32, is connected to the 3,000-volt mains, and the windings on the two rotors are connected together, the junctions being connected by wires *e* which pass along the hollow shaft *f* and crank *g* to the slip-rings *h*. It will be noticed that the slip-rings are outside the case of the motor, and are enclosed in a sheet-iron case *i* made in two parts, which are bolted together. This arrangement of the brushes and slip-rings has two advantages: it ensures easy access to the brush gear for purposes of inspection, and it allows more space for the working parts of the motors. Each motor has eight poles and, the frequency being 15, the synchronous speed is 225 revolutions per minute, corresponding to a locomotive speed of 40 miles per hour. When the motors are connected in cascade the synchronous speed is 112·5 revolutions per minute.

The primary motor is made larger than the secondary motor because it is more often and longer in circuit, and so is liable to heat up more. In order to economize space, as well as give less chance of the shaft bending, the bearings *j*, *j* project inwards under the rotors of each motor.

WIRING DIAGRAM FOR TWO-SPEED LOCOMOTIVE ON VALTELLINA RAILWAY

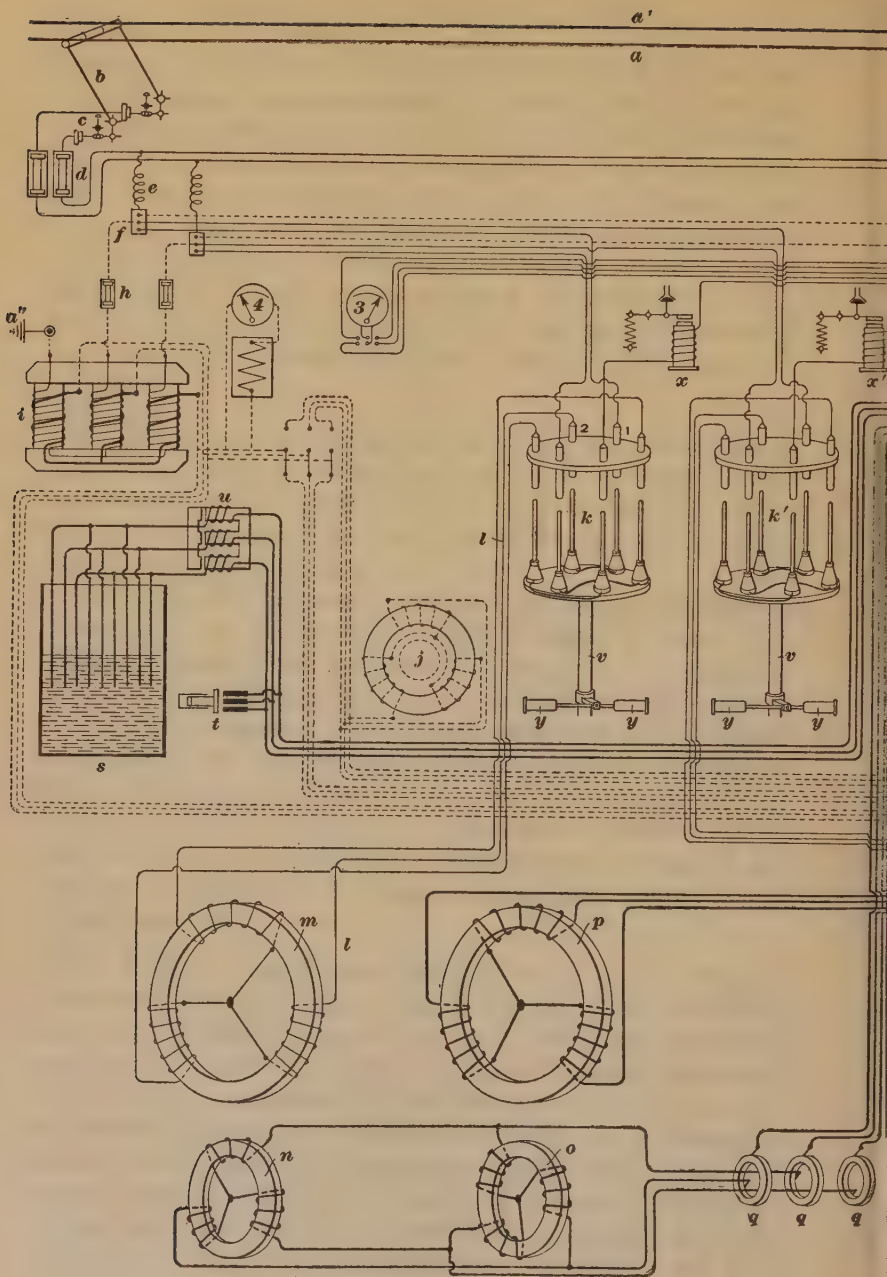
70. **Main Motor Circuit.**—A diagram of the connections of the electrical apparatus of a two-speed cascade locomotive is shown in Fig. 33. There are two supply conductors *a* and *a'*, and the track which is connected to earth is the third conductor, hence the earth connections are marked *a''* on the diagram. The path of the current in the main motor circuits is as follows for one phase: From conductor *a* through the collector *b*, switch *c*, which closes automatically when the collector *b* is raised to make contact with the supply conductors, fuse *d*, choking coil *e*, to terminal *f* on the bus-line. The automatic switch *c'* is shown in the open position as the collector *b'* is lowered. From *f*, current flows to contact 1 on the main switch *h*, and when this switch is closed the path is continued to contact 2, wire *l*, and the winding of stator *m* of the primary motor. The primary

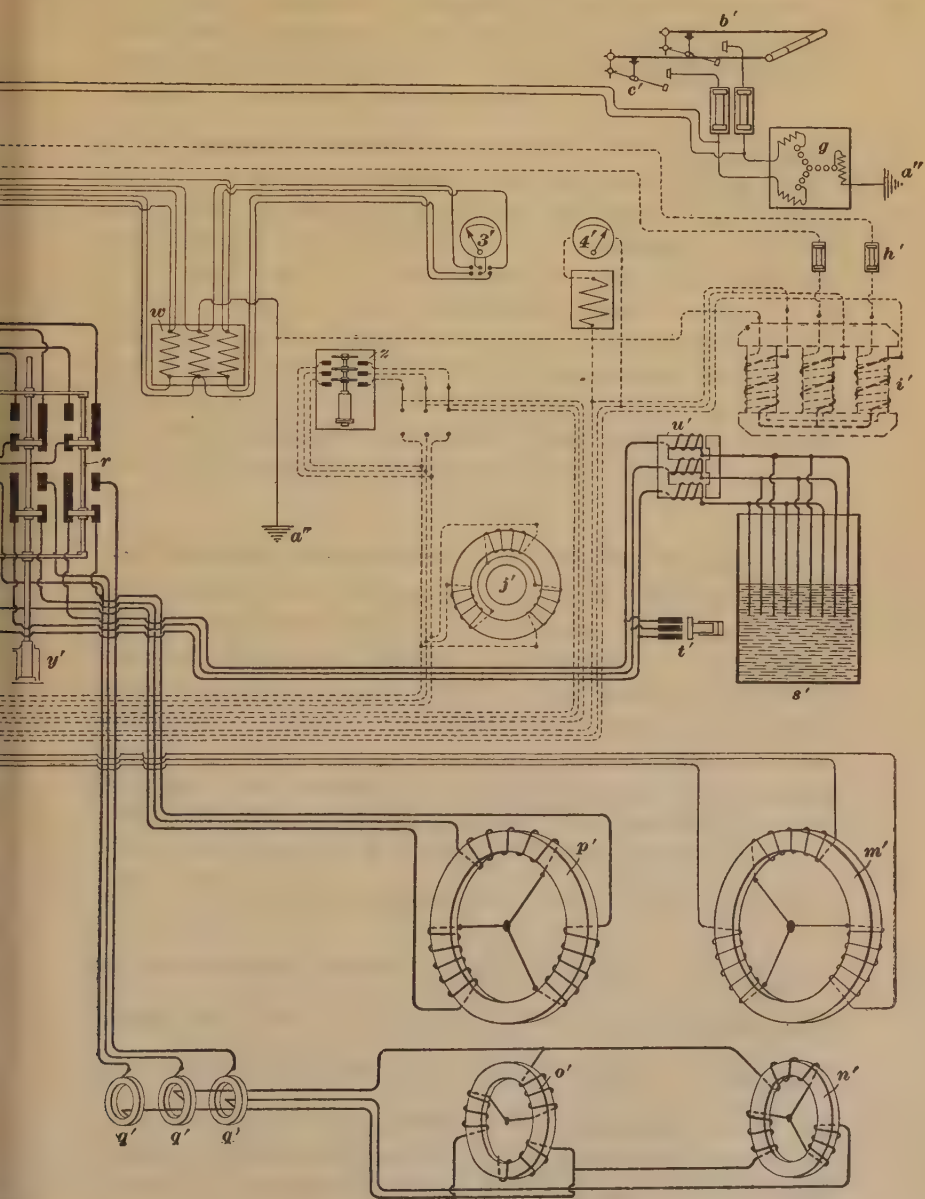
stator m' of the other compound motor is connected to the point f through the main switch k' . The rotor n of the primary motor is connected to the rotor o of the secondary motor, the stator of the secondary motor being indicated at p . The connections from the rotors n and o are carried to slip-rings q , and from these rings wires are carried to the switch r , which controls the connections to the liquid rheostats s and s' . The rotors n' and o' of the stators m' and p' are connected to slip-rings q' , which are in turn connected to terminals of the switch r . The devices for short-circuiting the liquid rheostats are shown at t and t' .

71. Safety and Reversing Devices.—The electromagnets u and u' are part of an automatic overload device which, if the load exceeds a predetermined value, opens a cock and allows the liquid to run out of the rheostat into the reservoir provided, thus inserting the resistance.

The leads from the main switches k and k' to the earthed conductor a'' are connected through the solenoids x and x' of automatic relays, which are arranged to open the main switches by releasing the compressed air in the cylinders v . The shunts w for the main ammeters β and β' are connected in the circuit as indicated. Each ammeter is provided with a double-pole double-throw switch, so that the current in any phase may be measured. The air cylinders y are provided in order that the main switches k and k' may be rotated through an angle of 60° and the connections to the motors changed for running in the reverse direction.

72. Action of Low-Pressure Switch.—Two sets of low-pressure mains enter the low-pressure switch r , Fig. 33. One set is from each of the main compound motors. From the remaining terminals of the switch r cables are run to the liquid rheostats s and s' . When the switch r is in the lower position, as shown, the resistances s and s' are connected directly to the stator windings p and p' , respectively, of the secondary motors, and the primary and secondary motors are thus operating in cascade. When the switch r is lifted to the upper position by compressed air in the cylinder y' acting on a piston, the rotor windings n and n' of





the primary motors are connected to the resistances s and s' , respectively, by means of the slip-rings q and q' , the primary motor thus running alone. The stator windings p and p' of the secondary motors are open-circuited.

73. Auxiliary Circuits and Apparatus.—From the junction f , Fig. 33, on the bus-line, connections are made through fuses h and h' and one winding of each of the three-phase transformers i and i' to the common junction of the windings. The return circuit is through the other windings to the other main conductors a' and a'' . The transformers supply current for the compressor motors j and j' . The compressor motors are controlled by an automatic switch z , which closes the circuit when the pressure falls to a fixed limit, and opens the circuit and stops the motor when the pressure rises to another limit. The voltmeters on the auxiliary circuit are shown at 4 and $4'$.

THREE-SPEED LOCOMOTIVE FOR VALTELLINA RAILWAY

74. Motors and Equipment.—The most recent locomotives for the Valtellina Railway are equipped with primary and secondary motors with different numbers of poles. The primary motor is wound for eight poles and the secondary for twelve poles. Each motor may be worked separately, or the motors may be worked in cascade, thus giving three economical speeds. The motors are connected in cascade by connecting the rotor of the eight-pole motor to the stator of the twelve-pole motor. With a frequency of 15 cycles per second, the cascade speed is $\frac{120 \times 15}{8 + 12} = 90$ revolutions per minute. With the twelve-pole motor alone in circuit, the speed is $\frac{120 \times 15}{12} = 150$ revolutions per minute, and with the eight-pole motor alone, the speed is $\frac{120 \times 15}{8} = 225$ revolutions per minute. These motor speeds correspond to locomotive velocities of about 16, 26, and 40 miles per hour, respectively. The motors are not of the compound type, but the cranks of the eight- and twelve-pole

motors are connected together by a driving bar, and drive the wheels by means of cranks and coupling rods, as in the case of the two-speed locomotive. The arrangement of the various controlling appliances is much the same as for the two-speed locomotive, with the exception that additional pieces of apparatus are required.

75. Arrangement of Motor Windings.—When the motors are in cascade, the voltage applied to the stator of the twelve-pole motor is that generated in the rotor of the eight-pole motor. When the twelve-pole motor is operating by itself, its stator receives the full line pressure of 3,000 volts. It is necessary,

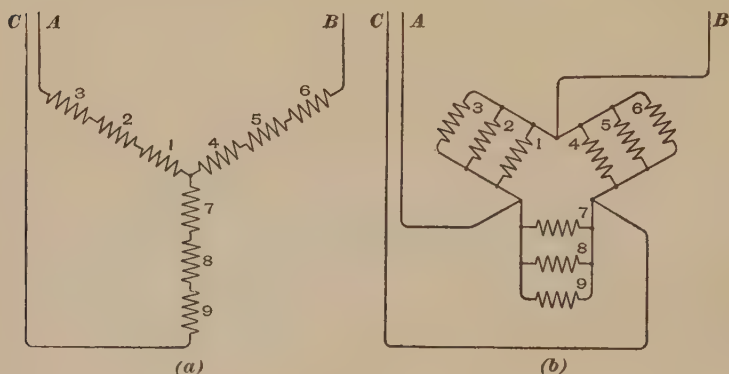


FIG. 34

therefore, either that the rotor of the eight-pole motor should be wound to give 3,000 volts when running in cascade, or that the stator of the twelve-pole motor should be reconnected for a lower voltage when used in cascade. The latter alternative has been adopted, and the connections used for the two voltages are shown in Fig. 34 (a) and (b). Each phase of the winding is divided up into three sections, as shown in view (a), phase *A* being divided into sections numbered on the diagram 1, 2, and 3, phase *B* into sections numbered 4, 5, and 6, and phase *C* into sections numbered 7, 8, and 9, the sections of each phase being connected in series, and the phases themselves being star- or **Y**-connected, for the full pressure of 3,000 volts. For cascade

working, the sections of each phase are connected in parallel and the phases themselves in delta, as shown in view (b).

76. Voltage Ratio.—If the correct voltage for each section of a phase of the motor winding is v volts, then, in the case shown in Fig. 34 (a), the voltage per phase is $3v$, and the voltage across the line is $3\sqrt{3}v$. In the case shown by Fig. 34 (b), the voltage across the line is equal to the voltage per phase, that is, to v . The ratio of the voltage for cascade connection to the voltage for direct connection is, therefore, $\frac{v}{3\sqrt{3}v} = \frac{1}{3\sqrt{3}} = .192$, approximately. The rotor of the eight-pole motor when running in cascade should therefore give $3,000 \times .192 = 576$ volts.

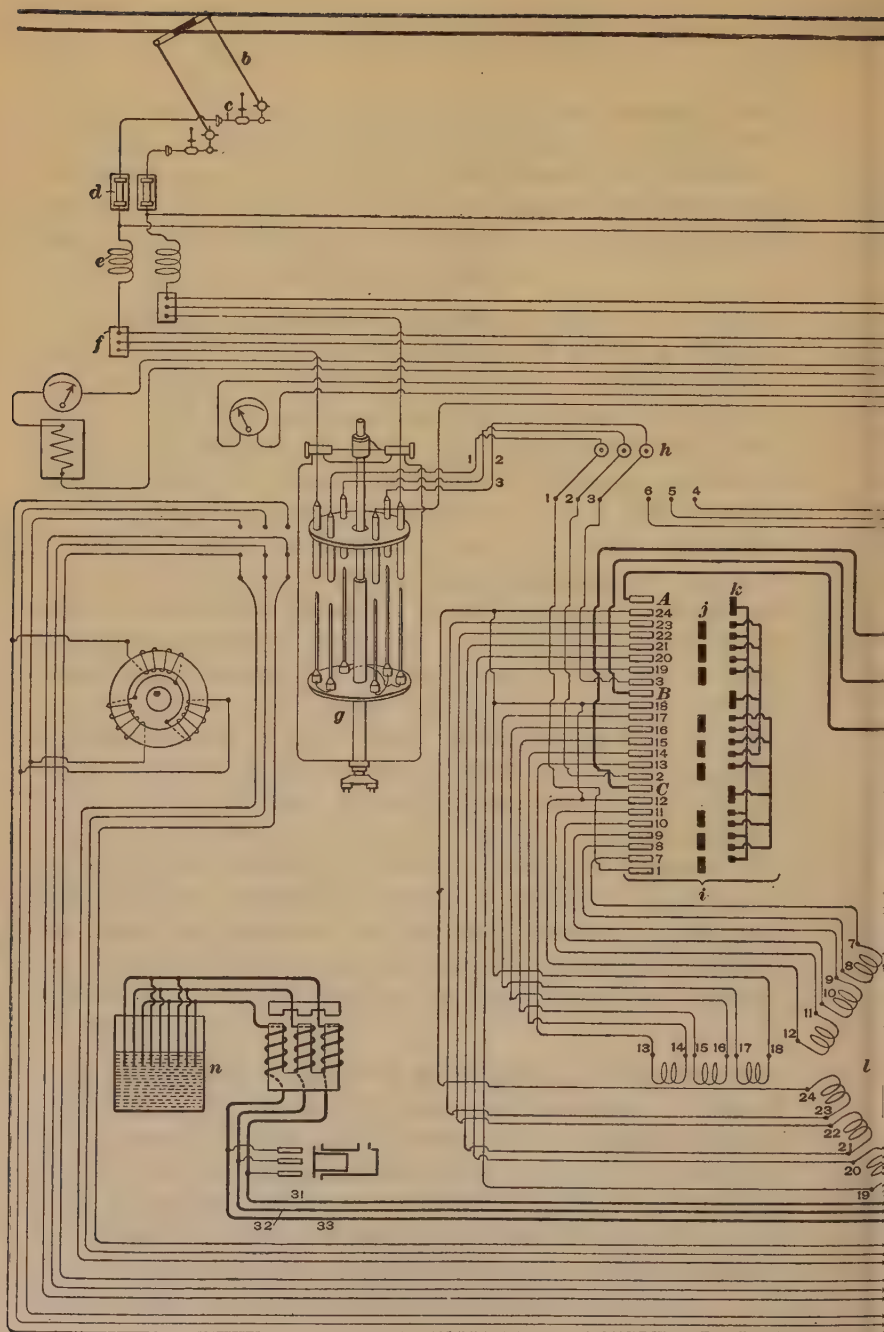
WIRING DIAGRAM FOR THREE-SPEED LOCOMOTIVE ON VALTELLINA RAILWAY

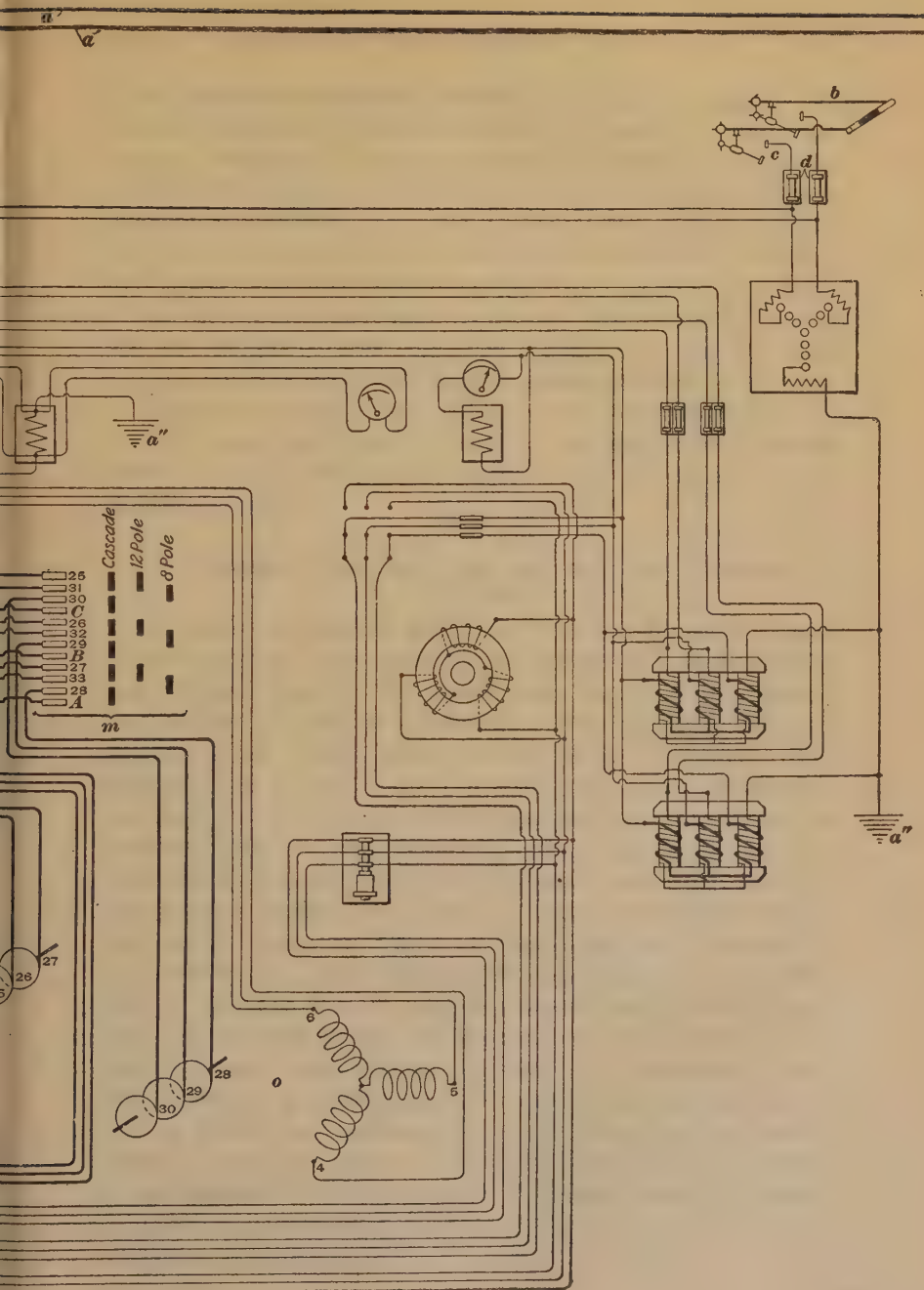
77. Cascade Connection of Motors.—The diagram of connections for the three-speed locomotive is given in Fig. 35. The compressor motor and auxiliary circuits are the same as for the two-speed locomotive, so that only the main circuits will be considered. The path through one phase winding when the motors are connected in cascade is as follows: From trolley wire a , through bow collector b , collector switch c , fuse d , choking coil e , terminal f , and, when main switch g is closed, to terminal 1 on the change-over switch h , which is placed on the contacts $4, 5$, and 6 , thus connecting the stator windings of the eight-pole motor o directly to the mains $1, 2$, and 3 . The slip-rings $28, 29$, and 30 of the eight-pole motor o are connected to the fingers $28, 29$, and 30 on the low-tension switch m , and these are joined by the contacts marked *cascade* to the fingers A, B , and C . These fingers are connected to similarly lettered fingers on the switch i . For example, finger A on switch i is connected by the contacts k to fingers $20, 22$, and 24 , and also to fingers $7, 9$, and 11 , the fingers being connected to similarly numbered terminals of the stator winding of the twelve-pole motor l . Similarly, finger B is joined to terminals $14, 16, 18, 19, 21$, and 23 of the stator winding, and finger C to terminals

8, 10, 12, 13, 15, and 17. In this way, all the sections of one phase are connected in parallel, and the phases are connected in delta, as shown in Fig. 34 (b). The slip-rings 25, 26, and 27, Fig. 35, of the twelve-pole motor *l* are connected by way of the similarly numbered fingers on switch *m* to the fingers 31, 32, and 33 which lead to the liquid resistance *n*.

78. Connection of Twelve-Pole Motor Alone.—For twelve-pole working of the motors the change-over switch *h*, Fig. 35, is in the position shown, and the current for one phase passes to contact finger 1 on the stator switch *i*. The set of contacts *j* are in contact with the fingers for twelve-pole connection, so that current passes from finger 1 to finger 7, and so to terminal 7 on the stator winding of the twelve-pole motor *l*. The contacts on switch *i* connect terminals 8, 9 and 10, 11, thus joining the various sections of the stator winding composing one phase in series. If the other phases are traced through, it will be seen that they are similarly connected to mains 2 and 3. The three phases are connected in star, the points 12, 18, and 24 being joined together. This gives the stator connections shown diagrammatically in Fig. 34 (a). Returning to Fig. 35, from the slip-rings 25, 26, and 27 of the twelve-pole motor, wires run to contacts 25, 26, and 27 on the low-tension switch *m*, the fingers of which are connected up by the set of contacts marked 12 *pole*, so that fingers 25, 26, and 27 are joined to fingers 31, 32, and 33, which are directly connected to the liquid resistance *n*. The controlling apparatus for this liquid resistance is the same as that previously mentioned in connection with the two-speed locomotive. The eight-pole motor *o* is in this case entirely disconnected.

79. Connection of Eight-Pole Motor Alone.—When the eight-pole motor *o*, Fig. 35, is to be run alone, the switch *h* is placed on contacts 4, 5, and 6, thus connecting the stator windings of the eight-pole motor to the mains 1, 2, and 3. The slip-rings 28, 29, and 30 are connected by the switch *m*, which is in the position marked 8 *pole*, to the terminals 31, 32, and 33 of the liquid resistance *n*. The twelve-pole motor is entirely disconnected, the switch *i* being in the off-position.





80. Method of Operating Motors.—In ordinary operation, the cascade connection, which corresponds to a speed of 16 miles per hour, is first used. Then the twelve-pole motor is used, giving a synchronous speed of 26 miles per hour, and lastly the eight-pole motor is switched into circuit, giving a full speed of 40 miles per hour. The main switch *g* must be opened, and all the resistance inserted in the liquid rheostat *n* before any change is made in the positions of switches *h*, *i*, or *m*. The switches *i* and *m* are, for simplicity, shown as drum controllers in Fig. 35; they do not, however, take this form in actual practice, on account of the high voltages in use. They are actually made after the style of quick-break knife switches. The main conductors are indicated by the letters *a*, *a'*, and *a''*, and the circuits for all phases are similar.

TWO-SPEED LOCOMOTIVES FOR SIMPLON TUNNEL RAILWAY

81. Speeds and Rating of Motors.—The first locomotives used on the Simplon Tunnel Railway were designed to give economical working speeds of 21 and 42 miles per hour by changing the numbers of poles on the motors. The motors are arranged for eight and sixteen poles, and as current is supplied at a frequency of 16 cycles per second, they have synchronous speeds of 240 and 120 revolutions per minute. The rotors are provided with six-phase windings, with six slip-rings, the connections being so arranged that, when the number of poles on the stator is changed, the raising of one set of brushes and the lowering of another set effects all the change that is required in the rotor circuit. Each locomotive is equipped with two 3,000-volt motors, each capable of giving a normal output of 450 horsepower at the high speed and 390 horsepower at the low speed. The maximum momentary output, that is, the momentary overload capacity, is 1,150 horsepower per motor, and the motors can be loaded continuously up to 575 horsepower per motor without excessive heating. The turning effort of the motors is transmitted to the three pairs of driving wheels by means of cranks and connecting rods in the same manner as for the Valtellina locomotive.

82. Distribution of Weight.—In the two-speed locomotives, which weigh 62 tons, the weight is carried on three pairs of driving wheels and two pairs of trailers, or pony wheels, as shown in Fig. 36. The load on each pair of trailers is 9 tons,

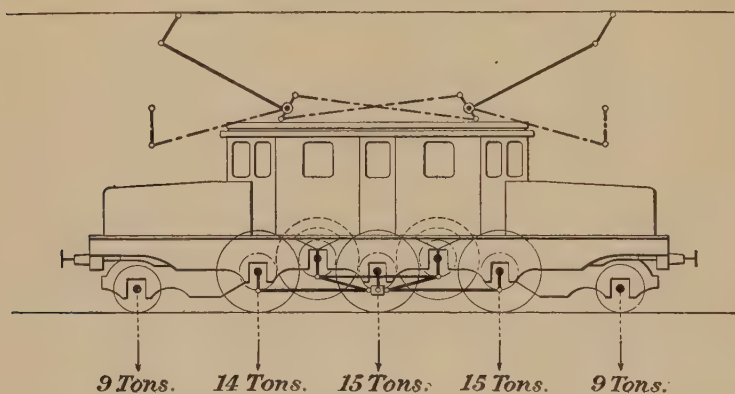
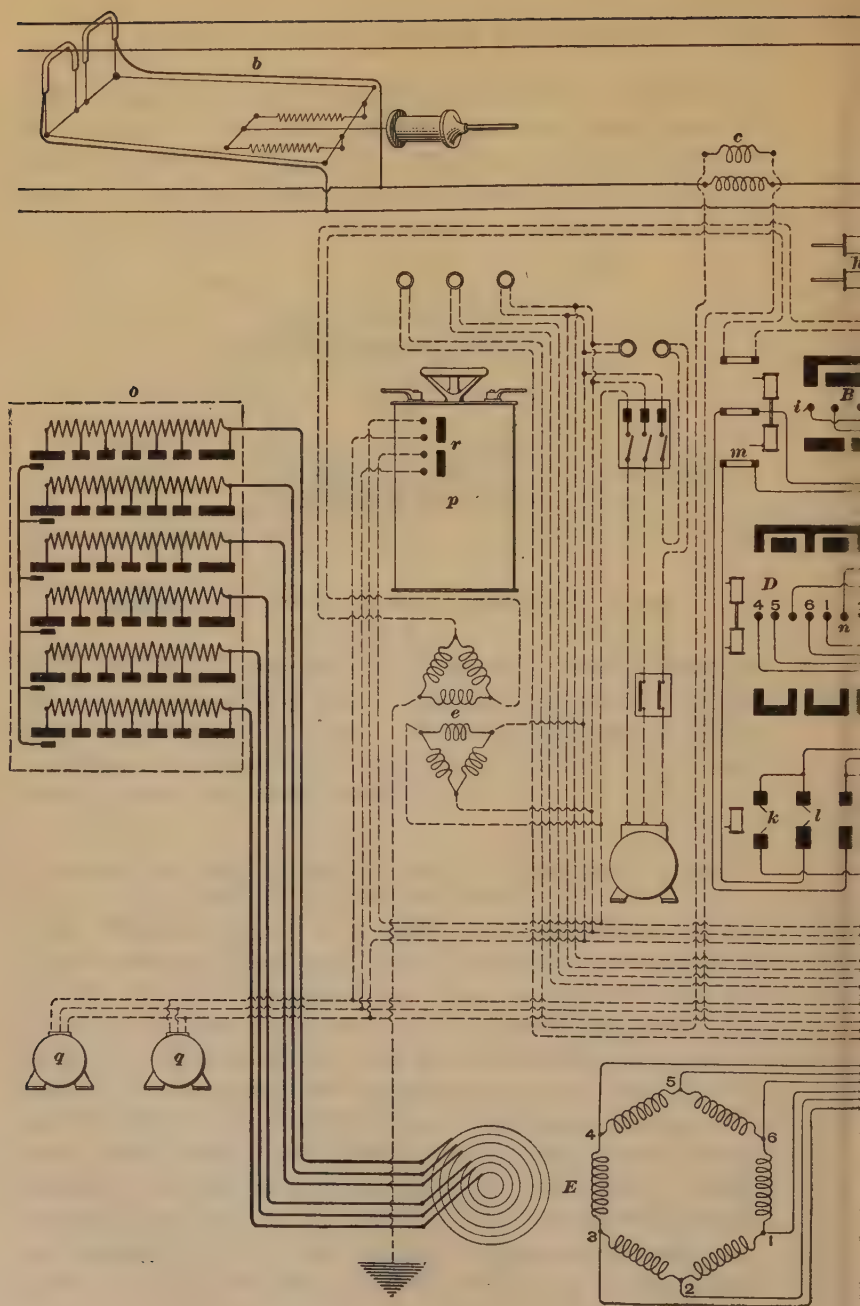


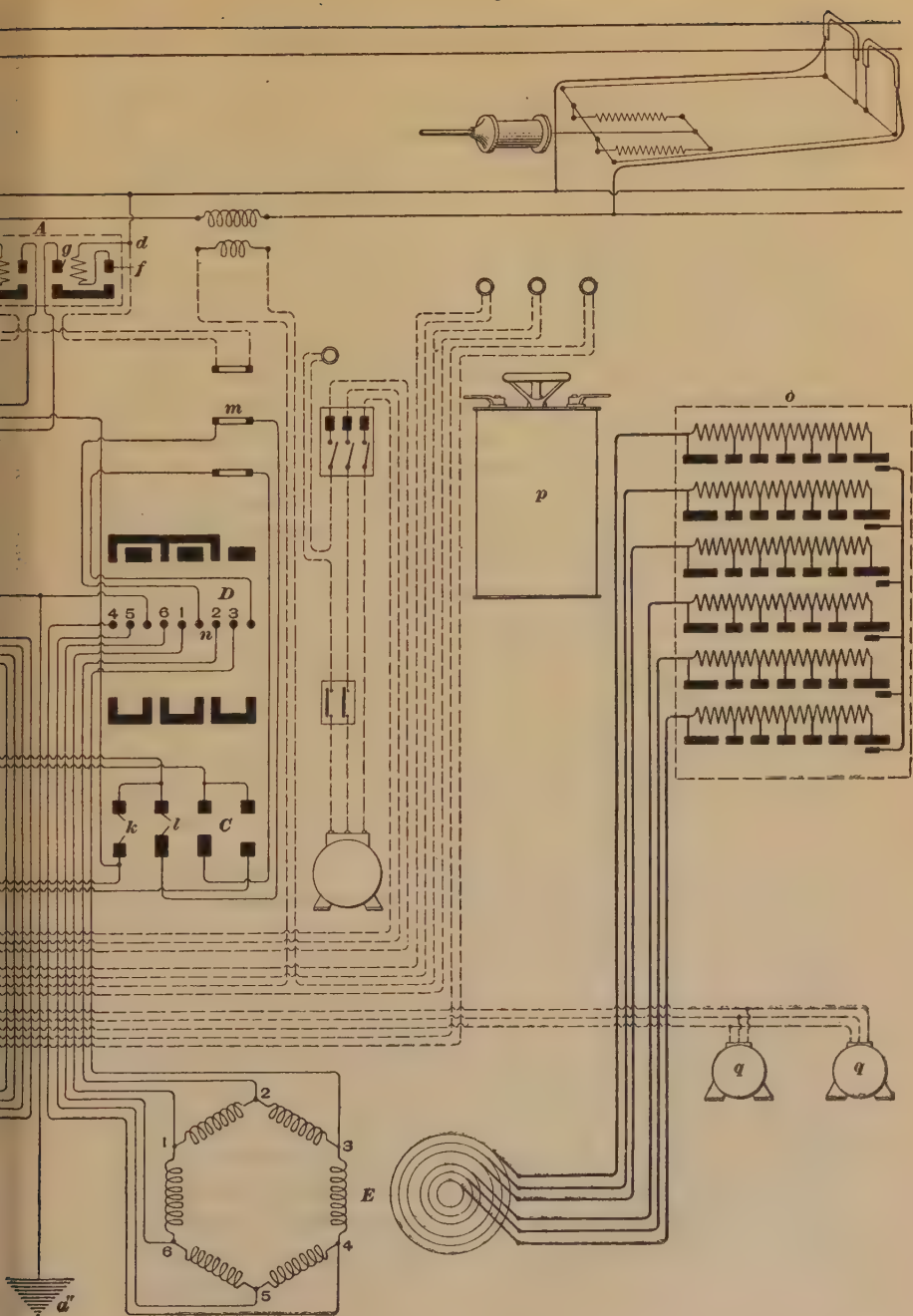
FIG. 36

leaving 44 tons to be carried by the driving wheels. Thus, out of a total of 62 tons, only 44 tons is available to cause the driving wheels to adhere to the track. The pony wheels are of service in guiding the locomotive round curves and in preventing rocking endwise on uneven track.

WIRING DIAGRAM FOR TWO-SPEED LOCOMOTIVE FOR SIMPLON TUNNEL RAILWAY

83. Motor Circuit for Low Speed.—The connections of one of the two-speed Simplon Tunnel locomotives are shown in Fig. 37. From trolley wire *a* the current passes down the bow collector *b*, through the primary of the current transformer *c* to the point *d*, where it divides, part going to the step-down transformer *e*, which supplies the compressor motors and the lighting and heating circuits, and part going to the main motors. The main current passes through the contacts *f* and *g* on the circuit-breaker *A*, which is operated by the pneumatic relay *h*, through contacts *i* and *j* on the reversing switch *B*, the fingers of which are supposed to be on the top row of contacts, through contacts *k* and *l* on the main switch *C* and fuses *m* to the contact





fingers n on the pole changer D . The fingers of the pole changer are assumed to be on the top set of contacts, so that current passes from fingers n to the fingers 1 , and to the points 1 on the stator windings of the motors E .

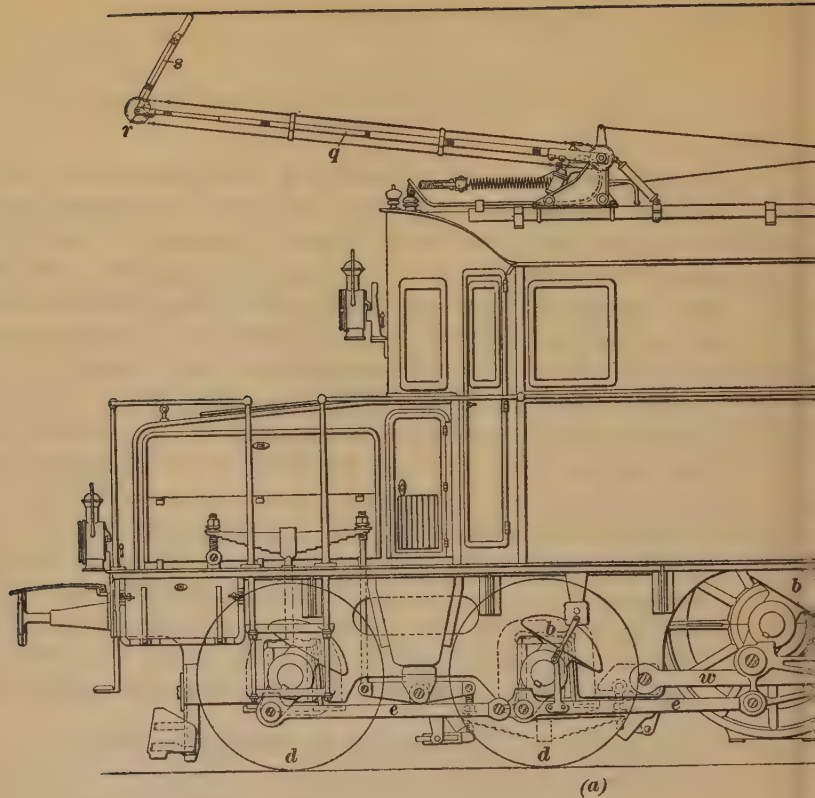
84. Trolley wire a' , Fig. 37, is connected to points $3, 3$ on the stator windings in a manner similar to that traced out for wire a , while the points $5, 5$ are connected to the earthed phase a'' of the system by way of the rails. Points $2, 4$, and 6 on the stator winding are connected together. This gives stator connections similar to those shown in Fig. 9, and in this case produces sixteen poles on the stator. Each motor is shown with two sets of slip-rings. When starting with the motors connected for sixteen poles, the brushes, which are connected to the eight-pole rotor winding, are raised from the rings, the brushes resting on the rings connected to the sixteen-pole winding remaining in place. Both sets of brushes are connected to the starting resistances o , which are cut into and out of circuit by the controllers p , which are geared together. The resistances are of wire, and are divided up into sections connected to contact studs; both resistances and contact studs are placed at some distance from the controllers, and are operated by means of gearing. The resistances are kept cool by means of fans driven by small motors q , put into circuit by controller contacts r .

85. **Motor Circuit for High Speed.**—For operation with the motors connected for eight poles, the lower set of contacts are placed under the fingers of the pole changer D , Fig. 37. The main circuit for one phase is then from trolley wire a , through circuit-breaker A and reversing switch B as before, to contact fingers n on the pole changer D . From fingers n , current passes to fingers 6 , and to the points 6 on the stator windings of the motors. By tracing through the circuits, it will be seen that trolley wire a' is connected to points 2 of the stator windings, and the earthed phase a'' is connected to points $4, 4$. This gives stator connections similar to those shown in Fig. 10, and in this case produces eight poles. The resistances in the rotor circuits are gradually short-circuited and the motors run at maximum speed.

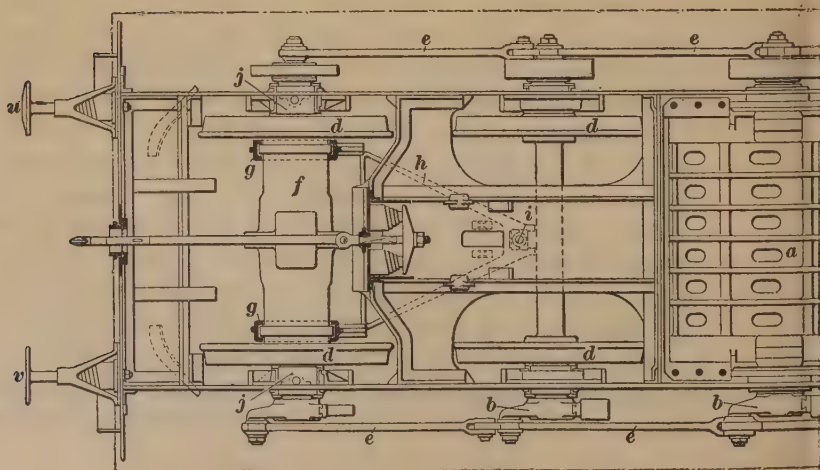
FOUR-SPEED LOCOMOTIVE FOR SIMPLON TUNNEL RAILWAY

86. Four-Speed Motor Equipment.—On the latest Simplon Tunnel locomotives provision is made for four speeds by means of double or compound motors. Each compound motor has two stator windings, and each winding can be connected to give two numbers of poles in the manner previously described. One stator winding gives sixteen and eight poles and the other twelve and six poles. These windings are referred to in the following description as the 16/8-pole winding and the 12/6-pole winding, respectively. As the rotors of both motors are of the squirrel-cage variety and are permanently short-circuited, starting cannot be effected by the insertion of resistance into the rotor circuit, as in the systems previously described. It is therefore necessary to reduce the voltage applied to the stator windings at starting. This is effected by means of an autotransformer provided with tappings, which enable the pressure to be reduced to 1,000 volts, that is, to one-third normal value at first, and to be gradually increased in steps of 200 volts up to the full value.

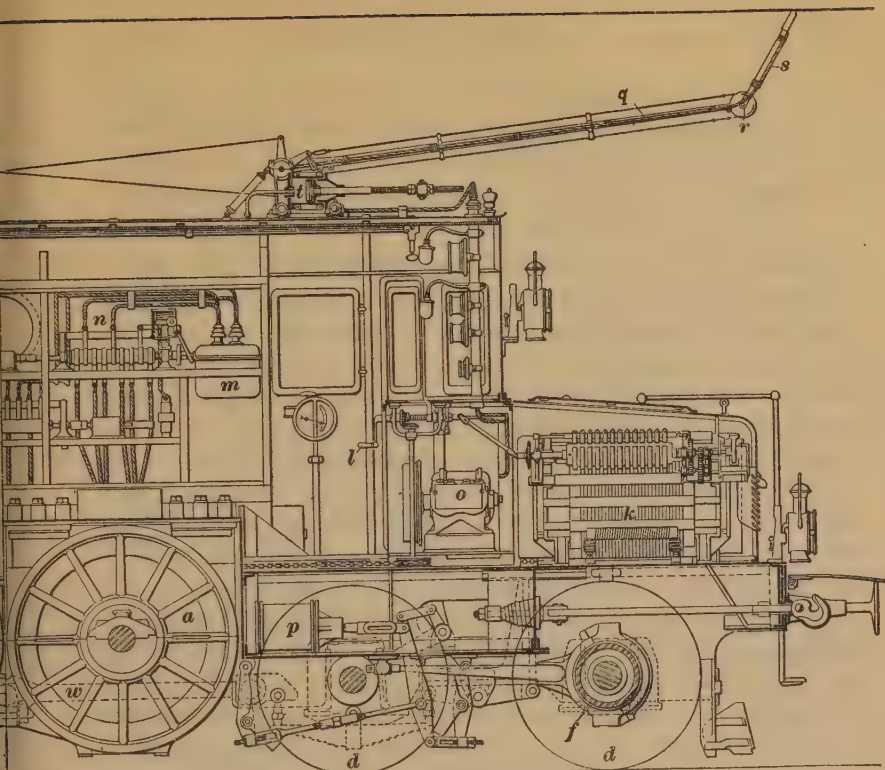
87. General Arrangement of Locomotive.—The arrangement of the various parts of the four-speed locomotive is shown in Fig. 38, view (*a*) being a side elevation and view (*b*) a plan showing the arrangement of one motor and bogie, view (*c*) a sectional elevation, and view (*d*) a plan showing the positions of autotransformers and switches. The motors *a* are supported from the frame of the locomotive, the weight being distributed by means of equalizing bars *w*. Both ends of the motor axles are provided with cranks and balance weights *b*. The cranks are connected together by driving bars *c*, and drive the four pairs of track wheels *d* by means of the coupling rods *e*. Each of the pairs of track wheels at the ends of the locomotive is carried on a hollow shaft *f* running in bearings *g*, the bearings and shafts being carried by a forked lever *h*, which is pivoted at *i*. The main driving axle to which the cranks are attached passes through the centre of the hollow shaft *f*, and runs in bearings *j* attached to the locomotive frame. The main axle



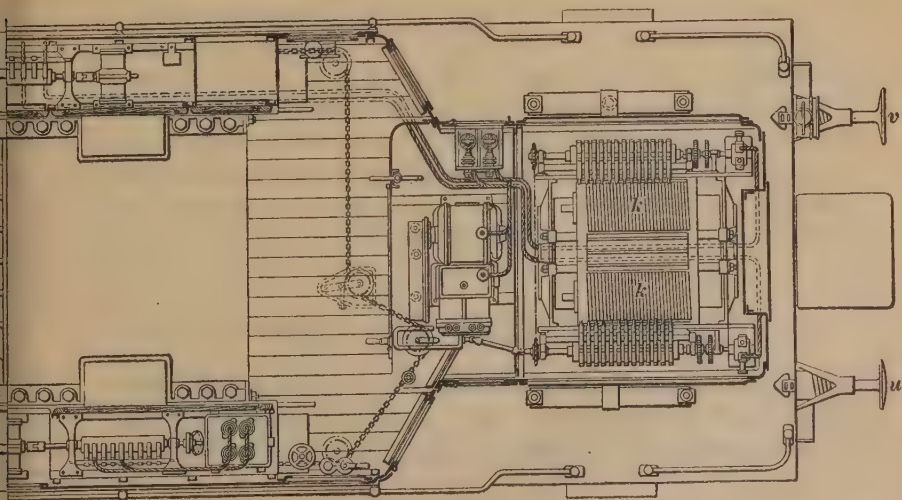
(a)



(b)



(c)



(d)

drives the hollow shaft and track wheels by means of helical springs, which form a flexible coupling, thus allowing the track wheels to follow curves without disturbing the system of connecting-rods. The helical springs also serve to hold the track wheels straight when running on a line without curves.

88. The autotransformers used for voltage regulation are shown at *k*, Fig. 38 (*c*) and (*d*) ; the handle by which the connections are changed so as to vary the voltage is shown at *l*. The autotransformers at the opposite ends of the locomotive are geared together by chains, so that identical tapings are used on both. One of the automatic high-tension switches is shown at *m*, and the pole-changing switch coupled to it at *n*. One of the compressor motors can be seen at *o* and a brake cylinder at *p*. The bow collectors, for taking the current from the trolley wires, consist of a main framework *q* to which is pivoted at *r* a smaller framework *s*. When the trolley wires are at the normal height above the ground, the main framework *q* remains in its highest position, resting against a stop, all inequalities in the height of the trolley wires being taken account of by the movement of the small frame *s* about the point *r*. When the trolley wires are low, however, as in the Simplon Tunnel itself, the main framework is also depressed. One of the compressed-air cylinders by which the collectors are raised is shown at *t*.

The locomotive is provided with a round buffer *u* and a flat buffer *v* at each end. It is necessary, in order to facilitate the passage of the train round sharp curves, to have a flat buffer always pressing against a round one, especially if the locomotive has to push as well as pull. To ensure that a flat and a round buffer shall always come together, buffers similarly situated must be rounded. Looking at the end of a vehicle, all the left-hand buffers must be rounded and the right-hand ones flat, or vice versa.

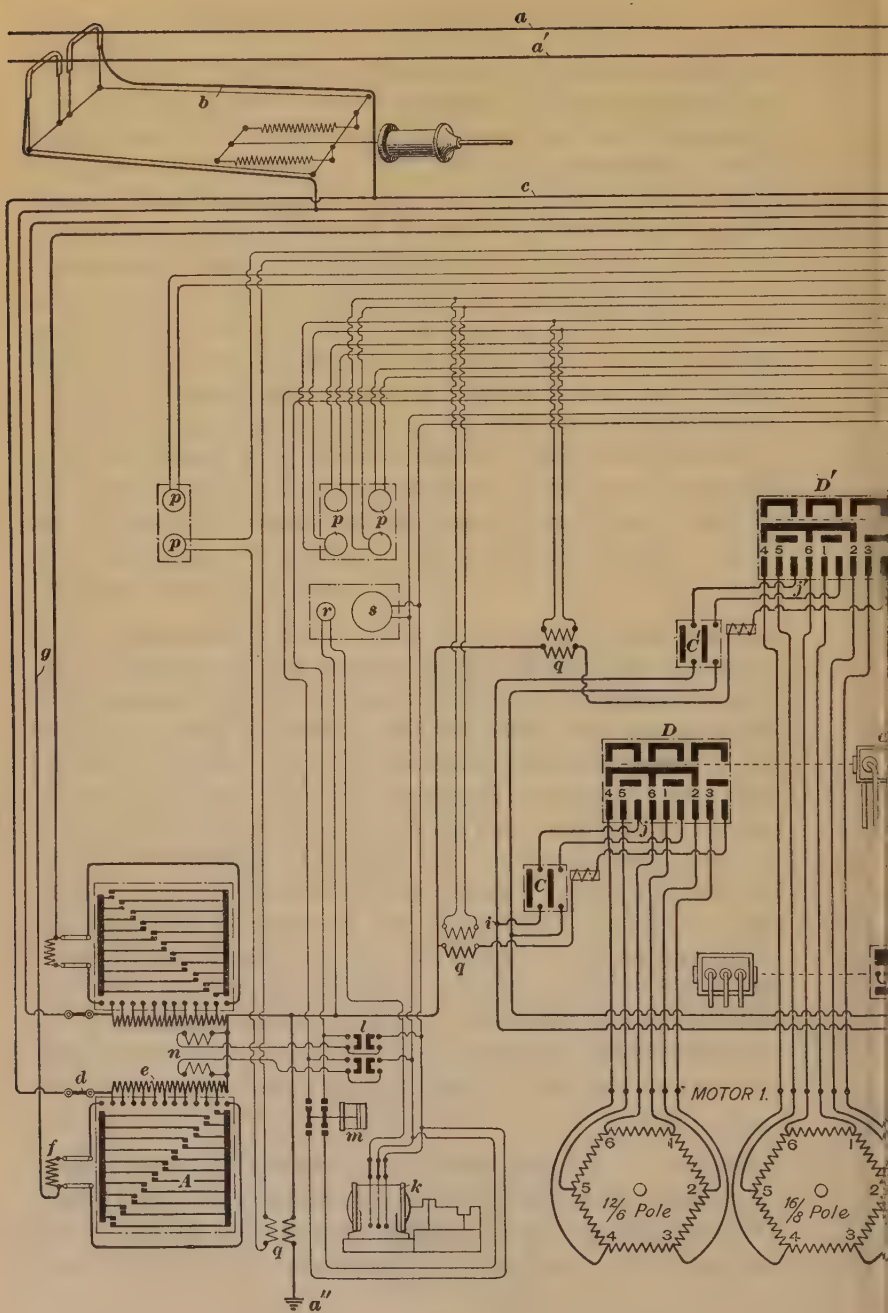
WIRING DIAGRAM FOR FOUR-SPEED LOCOMOTIVE FOR SIMPLON TUNNEL RAILWAY

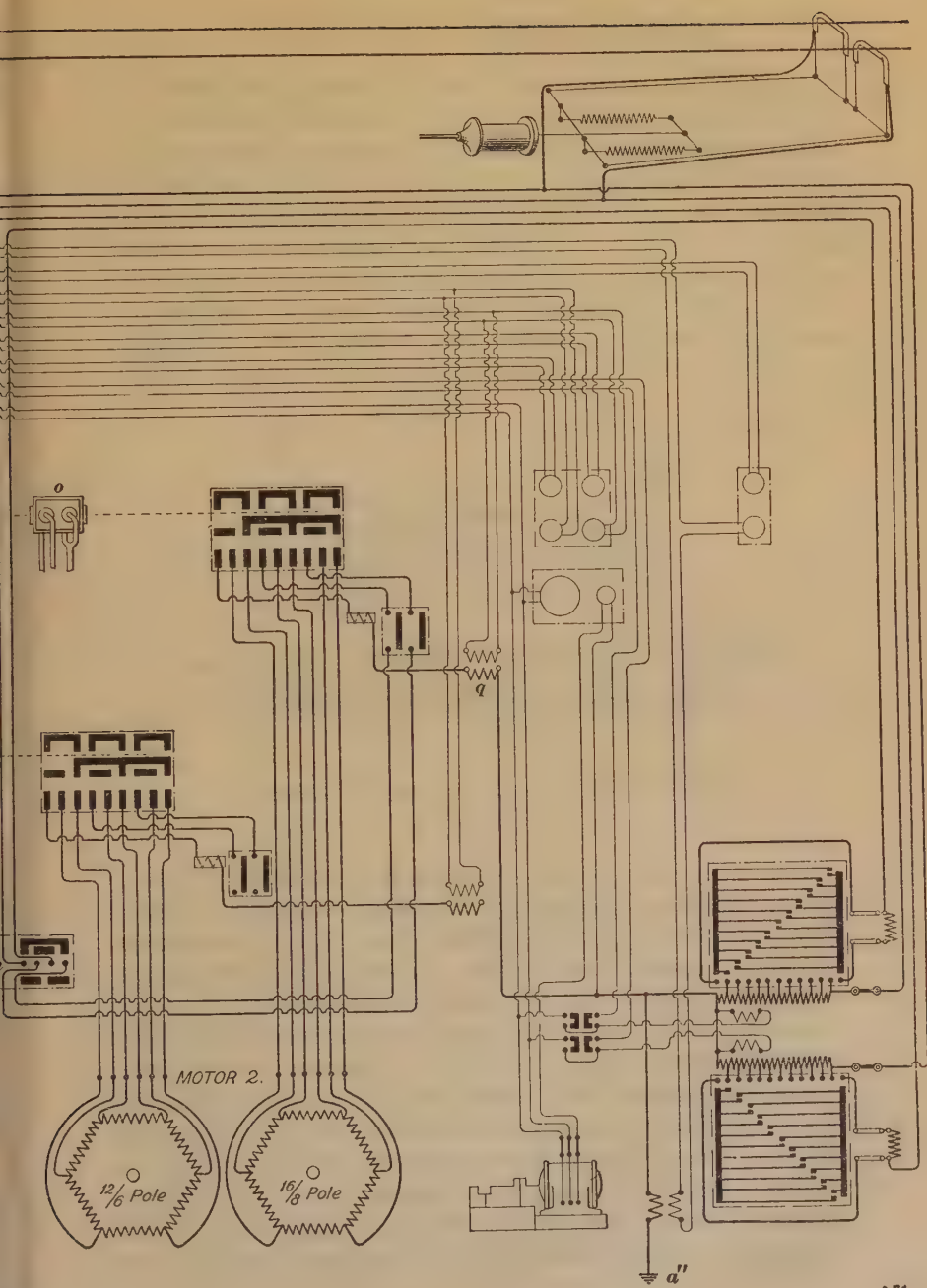
89. **Motor Circuits.**—The connections for a four-speed locomotive are given in Fig. 39. The current for one phase passes from the trolley line *a* down the arm *b* of the collector bow to

the bus-line c , and thence through the high-tension fuse d to the windings e of the autotransformer. This autotransformer is furnished with a step switch A , which enables connection to be made to theappings on the windings consecutively. When passing from one tapping to the next, each section of the autotransformer winding between the twoappings is momentarily short-circuited through the resistance f , which is of such a value as to prevent the current in the short-circuited section from attaining too great a value. The current passes from the particular tapping in use along the line g to contact h on the reversing switch B . Assuming the fingers of this switch to be on the lower set of contacts, current passes to the point i , where it divides. One part passes through the automatic high-tension switch C to contact finger j on the pole-changing switch D , the lower set of contacts of which are supposed to be in use. The current then passes to contact finger $\bar{j}$, and to terminal $\bar{j}$ on the 12/6-pole winding of motor 1.

90. Returning to point i , Fig. 39, where the current divides, the other part of the current passes through the automatic high-tension switch C' to contact finger j' on the pole-changing switch D' , then to finger $\bar{j}$ and terminal $\bar{j}$ on the 16/8-pole winding of motor 1. If the other phases are traced out, it will be seen that trolley line a' is connected to points 1, 1 on both 12/6- and 16/8-pole windings, and that points 3, 3 on these windings are connected to earth, that is, to the third phase a'' of the system. The connections are such that the twelve-pole and sixteen-pole windings are in parallel. Similarly, if the circuits are followed out with the upper set of contacts in the pole-changing switches D and D' in use, it will be found that the windings are connected so that one gives six and the other eight poles, the two windings being in parallel. The connections for motor 2 are shown on the right of the diagram, and are exactly as described for motor 1.

91. **Auxiliary Circuits and Apparatus.**—The compressor motor k , Fig. 39, is supplied through the hand-operated switch l and automatic pressure-regulating switch m from the step-down transformer n . The reversing and pole-changing switches and





the automatic high-tension switch are operated by compressed air, each pole-changing switch being directly coupled to the corresponding high-tension switch. The pole-changing switches for the two 12/6-pole windings are also mechanically coupled, as are those for the 16/8-pole windings. The compressed-air cylinders for operating these switches are shown at *o*. The ammeters *p* for indicating the current in the various main circuits are supplied from the secondary windings of current transformers *q*. The ammeter and voltmeter for the compressor motor *k* are shown at *r* and *s*, respectively

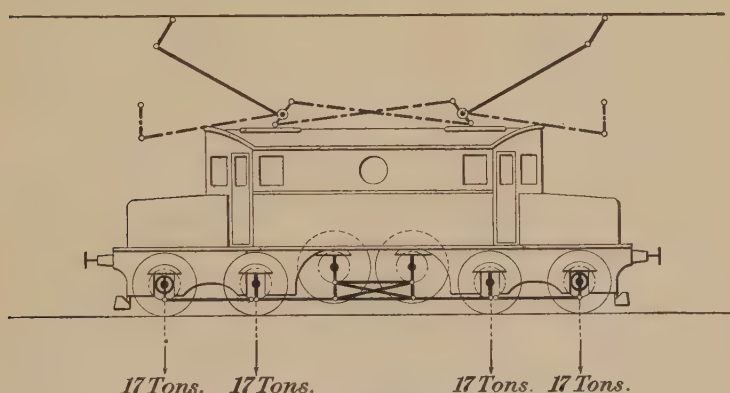


FIG. 40

92. Operation of Locomotive.—The operation of the locomotive is briefly as follows: At starting, the stator windings are in parallel, and are arranged for sixteen and twelve poles, respectively. By means of the autotransformer a potential difference of 1,000 volts is applied to the windings, and this is gradually increased as the speed rises until the full pressure of 3,000 volts is reached, the motors running at about the synchronous speed for sixteen poles. The sixteen-pole winding is then cut out, and the motors accelerate up to the twelve-pole synchronous speed. The pressure is next somewhat reduced, and the eight-pole winding is switched into parallel with the twelve-pole winding, the pressure then being gradually increased to full value. The next step is to switch out the twelve-pole

winding, thus causing the speed to rise to the eight-pole synchronous value. To attain the highest speed the pressure is again reduced, and the six-pole winding is placed in parallel with the eight-pole winding, the pressure is raised to full value, and finally the eight-pole winding is switched out.

93. Disposition of Weight.—There is a marked difference between the two-speed Simplon locomotives previously described and the four-speed ones at present under consideration. In the four-speed locomotives the total weight of 68 tons is equally divided, by means of an equalizing system of suspension, among four pairs of driving wheels, as shown in Fig. 40, each pair carrying 17 tons. The whole weight of 68 tons is thus available in producing adhesion. This is a great advantage where heavy gradients must be ascended.

OVERHEAD CONSTRUCTION FOR THREE-PHASE RAILWAYS

VALTELLINA RAILWAY

94. Usual Arrangement of Conductors.—It has already been stated that on most three-phase railway systems the rails are used as one conductor, and therefore only two overhead lines are required. This arrangement has the advantage of simplicity, but possesses a slight drawback in that the use of the rail makes the system unbalanced. Especially is this the case at high frequencies, because the impedance of the rails has a greater value than that of the overhead lines. When the rails are used as one conductor and two trolley wires per track are employed, the method of suspension for moderate voltages is almost identical with the span-wire construction used for direct-current tramway work, though the insulators used are heavier.

95. Method of Supporting Transmission and Trolley Wires. On the Valtellina Railway electrical energy is generated at 20,000 volts and transmitted by an overhead three-phase line to

transformer substations, from which energy at 3,000 volts is supplied to the working conductors. Where possible, the lines used to transmit the energy from the central station are carried on an extension of the poles which carry the trolley wire. When the track passes through a tunnel the transmission lines are carried on separate poles outside the tunnel. The contact wires are carried above the rails at a height of nearly 20 feet, which is reduced to 15.75 feet in tunnels. The construction, which is adopted for a single track on curves of less than 1,125 yards radius, is shown in Fig. 41. The supporting poles *a*, *a'* are connected by a cross-beam *b*. The insulators *c* supporting the 20,000-volt transmission line are carried by iron supports on an extension of the pole *a'*. The trolley wires *d* are supported from insulators *e* made of a strong insulating compound known as *ambroin*. These insulators are attached to steel span wires *f*, which are fastened to porcelain insulators *g* bolted to the poles *a*, *a'*. The outline of the rolling stock used on the line is shown dotted at *h*.

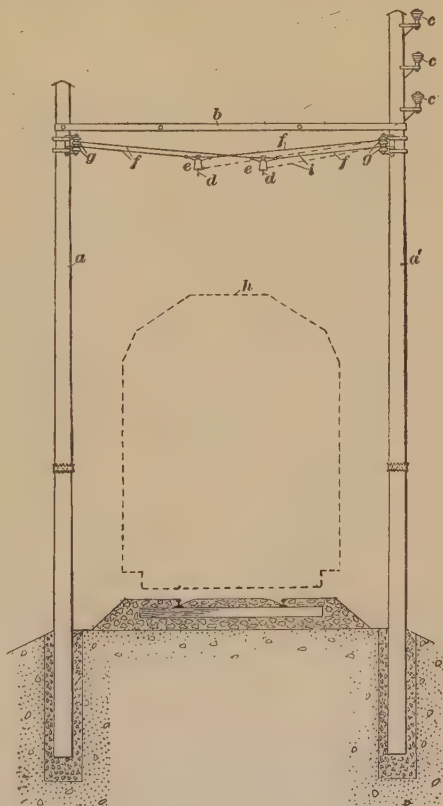


FIG. 41

96. Where there are no curves, or where the radius of curvature is greater than 1,125 yards, the trolley wires are supported

from brackets carried by single poles, as shown for a double track in Fig. 42. The various parts are lettered as in Fig. 41.

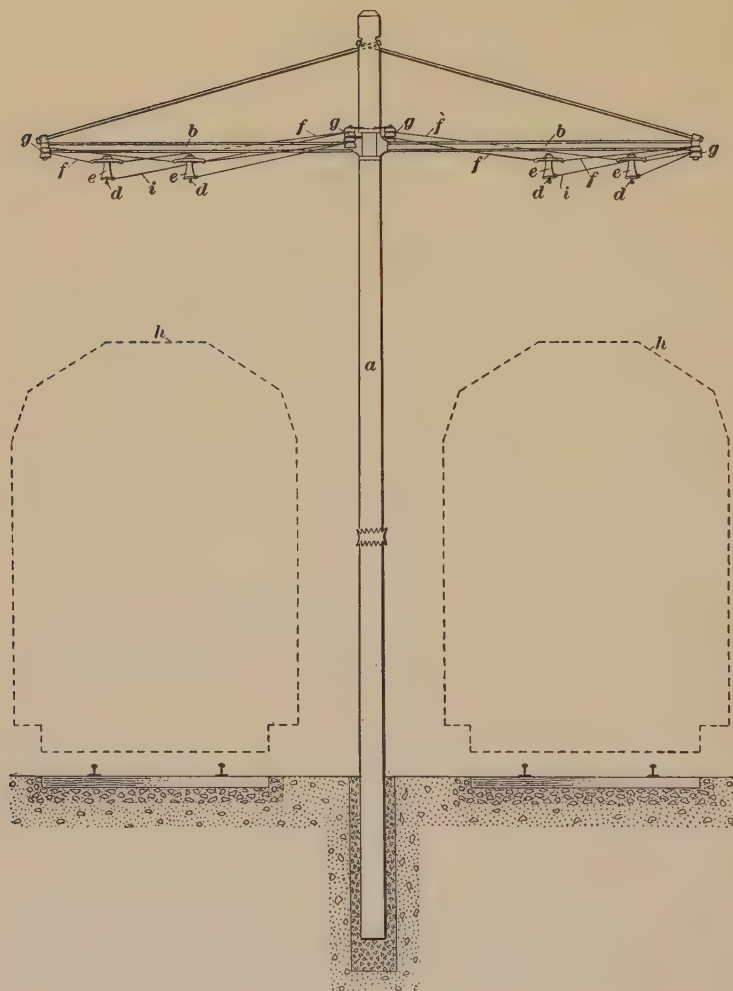


FIG. 42

The 20,000-volt transmission lines are carried on separate poles. In all cases the poles are set in concrete.

97. **Trolley Insulators.**—The construction of the trolley insulator *e*, Fig. 42, is shown in detail in Fig. 43 (a), (b), and (c). The iron bolt *a* is almost completely covered by the ambroin insulating material *b* which is moulded round it. This ambroin-covered bolt is inserted in an iron petticoat *c*, which is provided with grooved arms *d*. To the bottom of bolt *a* is attached a clip *e* consisting of two cheeks of galvanized iron, between which the

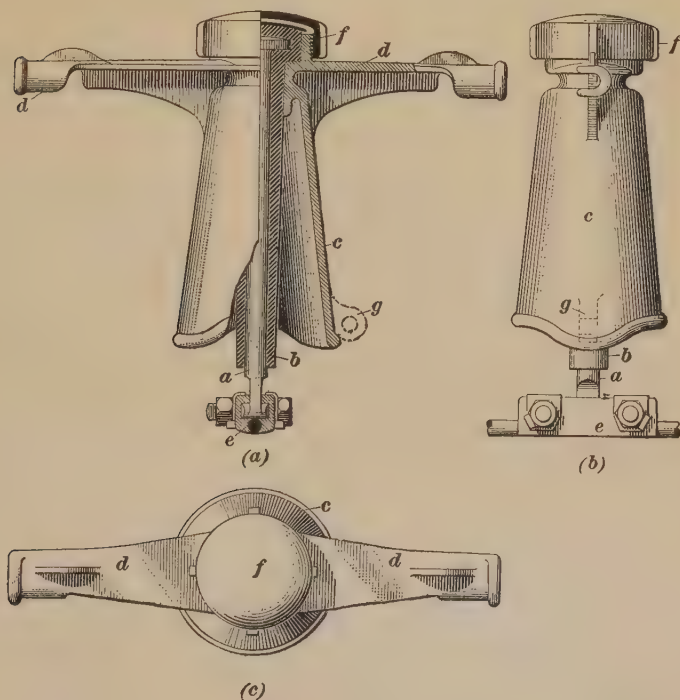


FIG. 43

trolley wire is clamped. The top of the ambroin-covered bolt is held in place and protected from the weather by the cap *f*, which screws on to the iron frame. The span wire from which the insulator is suspended passes along the groove in the arms *d* and round the top of the petticoat *c*, as in the ordinary hanger for direct-current tramway trolley wires. On curves, the base of the iron petticoat is provided with an eye, as shown dotted

at *g*, to which is fastened a wire which ties the insulator to the post. This is necessary in order to balance the side pull of the trolley wire. The tie-wires are indicated by the lines *i* in Figs. 41 and 42.

98. Transmission and Span-Wire Insulators.—The 20,000-volt lines that supply energy to the substations are carried on porcelain insulators made in

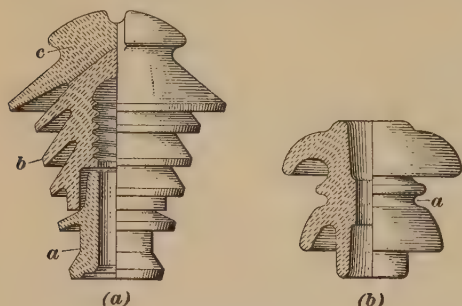


FIG. 44

three parts, as shown at *a*, *b*, and *c*, Fig. 44 (*a*). The parts of the insulator are held together by means of cement, and a screw thread is provided on section *b* for the insulator pin.

The span wires which support the working conductor are fastened to porcelain insulators of the form shown in Fig. 44 (*b*). The span wire is tied round the insulator in the groove *a*, and a bolt through the hole supports the insulator.

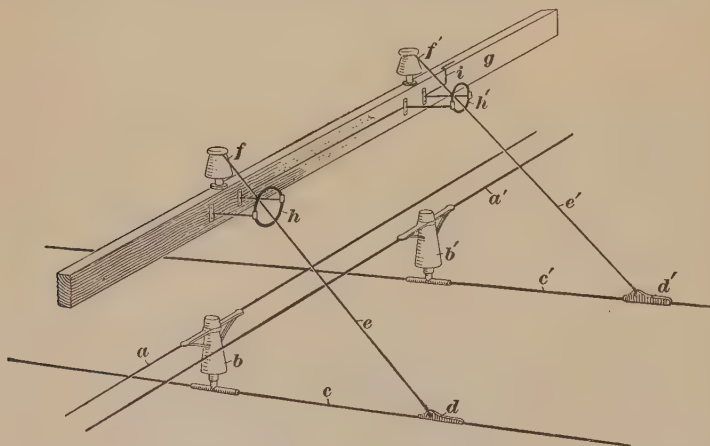


FIG. 45

99. Earthing Device.—On account of the high voltage used on the trolley wires, it becomes necessary to provide some device

for instantly earthing the trolley wire if either that or the span wire should break. The method adopted at level crossings on the Valtellina Railway is shown in Fig. 45. The span wires are shown at a, a' , the insulators at b, b' , and the trolley wires at c, c' . The trolley wires have attached to them at the points d and d' two short lengths of wire e, e' , which terminate at the insulators f, f' on the cross-bar g . These wires pass through metal loops h, h' which are connected to the wire i , the other end of which is earthed. If either of the span or trolley wires should break, the wire e or e' makes contact with one of the metal loops h, h' and earths the trolley wire to which it is connected.

OVERHEAD CONSTRUCTION ON SIMPLON TUNNEL RAILWAY

100. The overhead construction in the Simplon Tunnel is another example of the use of span wires. On account of the limited space available, a compact and strong construction was necessary, and exceptional care had to be taken with the insulation on account of the great heat and dampness of the tunnel. The construction adopted is shown in Fig. 46, each overhead conductor being composed of two wires in parallel. The trolley

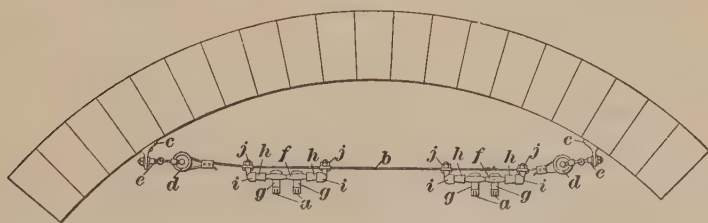


FIG. 46

wires a are supported from a copper-plated steel span wire b , which is stretched between insulators d fastened by means of eyebolts e to gunmetal studs c . The studs are grouted into the roof of the tunnel. As only one span wire is used, each trolley wire is doubly insulated from the span wire in order to secure effective insulation between the phases. The trolley wire is held in a clip, or ear, which is fixed in a gunmetal cross-bar f

by means of ebonite-insulated bolts *g*. Porcelain insulators *h* are screwed on at each end of the cross-bar, a layer of hemp and asbestos being inserted between the screw and the porcelain. The insulators *h* are screwed to gunmetal caps *i*, a layer of rubber being placed between the two, and the caps are fastened to the span wire *b* by gunmetal clamps *j*. The design of these insulators makes quick repairs possible, as each part is separately replaceable. Each insulator is capable of withstanding a pressure of 40,000 volts, which is more than sufficient for a working pressure of 3,300 volts, even under the unfavourable conditions prevailing in the tunnel. Tests have shown that the leakage from the trolley wires is very small.

101. The overhead work outside the tunnel is supported by light structures of steel tube, as shown in Fig. 47. The support *a*

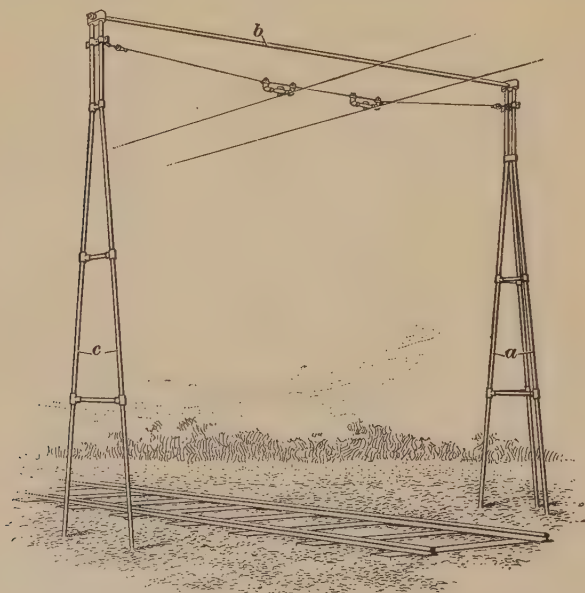


FIG. 47

on one side of the track is a tripod, and is connected by the tube *b* with a two-legged support *c*. This gives an exceedingly light

and compact structure, which is very rigid and strong. Where a large number of tracks are to be spanned, tripods are used at each side, and are connected by horizontal tubes to two-legged supports between each track.

102. Joints and Crossings.—The arrangement of two overhead wires necessary for three-phase working leads to difficulties at places where two tracks join or cross. On railways where junctions are numerous, this consideration is important, and causes the three-phase system to compare unfavourably with other systems. At large stations where complicated junctions occur, it is doubtful as yet if the advantages of the three-phase as compared with other systems would outweigh this drawback, but for less exacting cases and for main line work, there is no doubt that the adoption of the three-phase system is well worth consideration.

In many respects the difficulties experienced in arranging the overhead lines at junctions, crossings, etc., are similar to those encountered on direct-current railways employing third and fourth rails, somewhat modified, however, by two facts: first, that the overhead lines do not follow the line of the track exactly, as is the case with conductor rails, and, second, that it is desirable for mechanical reasons to keep overhead wires continuous, whereas conductor rails must be discontinuous where they cross the running rails. The reason for keeping the overhead wire continuous is that it is undesirable to let the bow travel freely in the air. If there were a gap in the overhead line, the wires at both ends of the gap would have to be terminated and inclined in such a way that there would be no difficulty in the collector coming on to the wire again, even at high speeds. Continuity is obtained by the use of a dead wire, which is insulated from the live wire by strips of impregnated wood. It must, of course, be so arranged that no bow can touch two live wires of different phases, and that no dead wire can short-circuit two bows of opposite phases. It is further desirable that a car shall be able to start, if required, from a junction, and therefore the length of any dead section must be less than the distance between the collectors at the two ends of the locomotive or coach,

ALTERNATING-CURRENT RAILWAYS

(PART 2)

SINGLE-PHASE RAILWAYS

SERIES ALTERNATING-CURRENT MOTOR

INTRODUCTION

1. **Types of Motors.**—The advantages obtained by the use of alternating current for long-distance railway lines with heavy trains are possessed by the single-phase system as well as by the three-phase system. The development of the single-phase system was, however, long delayed by the lack of a suitable single-phase alternating-current motor, and at present only two types are in use ; these are the *alternating-current series motor* and the *compensated repulsion motor*. The alternating-current series motor was first developed, in 1902, by the Westinghouse Electric and Manufacturing Company of America, but is now made by many other firms. It will work satisfactorily with either alternating or direct current. The compensated repulsion motor, or *Winter-Eichberg motor*, as it is sometimes called after its inventors, is manufactured by the Allgemeine Elektrizitäts Gesellschaft, in Germany.

OPERATION OF SERIES MOTOR ON ALTERNATING CURRENT

2. **General Construction of Motor.**—The alternating-current series motor is similar in construction to a direct-current series motor, but is fitted with laminated field cores and yoke as well as laminated armature core, in order to prevent excessive loss due to eddy currents which would be set up in a solid mass of iron by the reversals of magnetic flux. In order to improve commutation by reducing the current in the armature coils which are short-circuited by the brushes, the leads from the coils to the commutator segments are made of high-resistance material, and are much longer than they would be for a motor designed to operate on direct-current circuits. The inductive effects of the armature are more or less completely neutralized by a *compensating* or *neutralizing winding*, which is distributed in slots in the pole faces. The current circulates in the compensating winding in a direction opposite to that in the adjacent armature conductors.

3. **Direction of Rotation.**—When an alternating current flows through the field and armature windings of a series motor, the polarity of the field pole pieces and the direction of the current

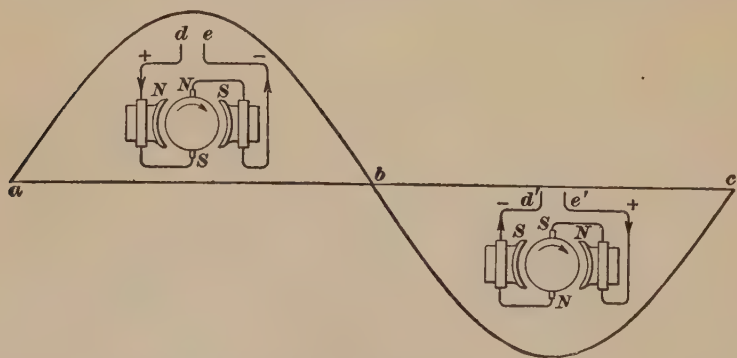


FIG. 1

in the armature conductors change at practically the same instant, so that the relation between them is unchanged and continuous rotation in a given direction is therefore maintained. In Fig. 1, curve *abc* represents one cycle of an alternating

current. In the portion of the cycle $a b$, the current is assumed to flow from motor lead d to lead e , resulting in the north N and south S polarity of fields and armature cores and the direction of rotation shown by the arrow. At b , the direction of flow of current is reversed; it now flows from lead e' to lead d' , thus reversing the polarity S and N of field poles and armature poles, but not the direction of rotation, which remains unchanged, as indicated. In the case of an alternating-current motor, as well as of a direct-current series motor, the direction of rotation is not reversed where both the field terminals and the armature terminals are reversed, but the rotation is reversed when either the field terminals or the armature terminals are reversed.

COMPENSATION FOR INDUCTANCE AND ARMATURE REACTION

4. Effects of Inductance.—When a current flowing through a coil changes in value, the number of lines of force embraced by the coil also changes, and this change in the number of lines sets up an E.M.F. in the coil. The induced virtual E.M.F. is proportional to the inductance of the coil and to the frequency of the change in current. In a motor used on an alternating-current circuit, the induced E.M.F. tends to make the current supplied to the motor lag behind the voltage impressed on the motor terminals, thus giving a low power factor. As it is desirable to have as high a power factor as possible, the inductance of the motor windings is made as small as possible.

In the case of the main field windings of a series motor, the induced E.M.F. is reduced to its lowest value by reducing the number of turns of the field coils to the minimum which will give the necessary magnetic flux with the current flowing.

5. Action of Compensating Winding.—An extra field winding is provided on alternating-current series motors, the effect of which is to neutralize or compensate for the inductive effect of the armature coils, and the winding is therefore called a **compensating winding**. The compensating winding, main field winding, and the armature are all connected in series. The compensating action depends on the fact that, if means are

provided for subjecting the coil, the inductance of which is to be neutralized, to the effects of induction from a second coil having an opposing magnetic flux, both coils will be practically free from inductance, and the same value of either direct or alternating E.M.F. will send the same current through the coils. This is the effect of the action of the compensating coils on the armature coils, and the armature coils on the compensating coils. In addition to reducing the inductive effect of the armature coils and compensating coils, and thereby improving the power factor of the motor, the current in the compensating winding so neutralizes the armature reaction that proper commutating conditions may be secured with fewer turns on the field winding, and thus with a weaker field, than would otherwise be possible.

6. The action of the compensating winding is shown in Fig. 2, which is the development of a portion of the windings

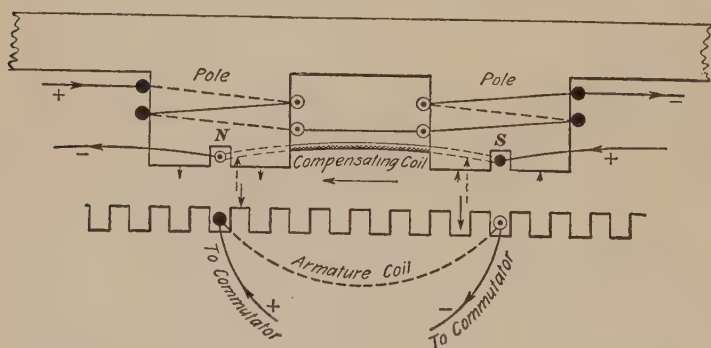


FIG. 2

of a compensated single-phase alternating-current series motor. The direction of motion of the armature core is indicated by the large horizontal arrow. Only one armature coil and its corresponding compensating coil are shown. In the actual motor there are numerous armature coils and compensating coils, the armature coils being placed in slots in the armature core and the compensating coils, having much the same distribution, in slots in the pole faces. Two pole pieces and two main field coils are shown, as well as the resulting polarity,

north *N* and south *S*, of the poles when the current is flowing through the field coils in the direction indicated by the arrowheads.

7. In order to obtain rotation in a given direction, there must be a certain relation between the polarity of the pole pieces and the direction of current flow in the armature conductors under the poles. With the polarity as shown in Fig. 2, and the indicated direction of rotation, the current in the armature coil flows in a counter-clockwise direction when viewed from the lower portion of the illustration. The current is an alternating one, so that, while the coil is passing from contact with one brush to contact with the next, the current through the motor windings may reverse several times. At the instant under consideration, the current in the armature coil tends to set up a magnetic flux in the direction indicated by the full-line vertical arrows.

8. The compensating coil is so connected that the current flowing through it has a tendency to set up a magnetic flux in the direction indicated by the vertical dotted arrows, Fig. 2. These two magnetic fluxes oppose each other. If the current reverses, both magnetic fluxes are reversed in direction, and therefore still oppose each other. These fluxes practically neutralize each other in their action on the sets of coils. The compensating coil is not always connected in series with the main motor windings. In some types of motor it has no external connections at all, and is merely short-circuited on itself. In this case it acts as the short-circuited secondary of a transformer, and is quite effective in neutralizing the effect of inductance of the armature.

9. **Relative Arrangement of Coils.**—The relative arrangement of armature, pole pieces, main field coils *a*, and compensating coils *b*, *c*, *d*, *e* for a four-pole motor is shown in Fig. 3. The armature, if of large size, is usually parallel-wound and arranged for more than a four-pole field. It is assumed that at a given instant the alternating current is flowing in such a direction through the main exciting field coils, the armature, and the

compensating coils as to tend to make the top and bottom pole pieces north poles N and the side pole pieces south poles S ; to make two north poles N_a and two south poles S_a at the points indicated on the armature core; and to make the inner sides of compensating coils e and c north poles N_c , and the inner sides of compensating coils b and d south poles S_c . The directions of these various sets of lines of force are indicated by short arrows and arrowheads.

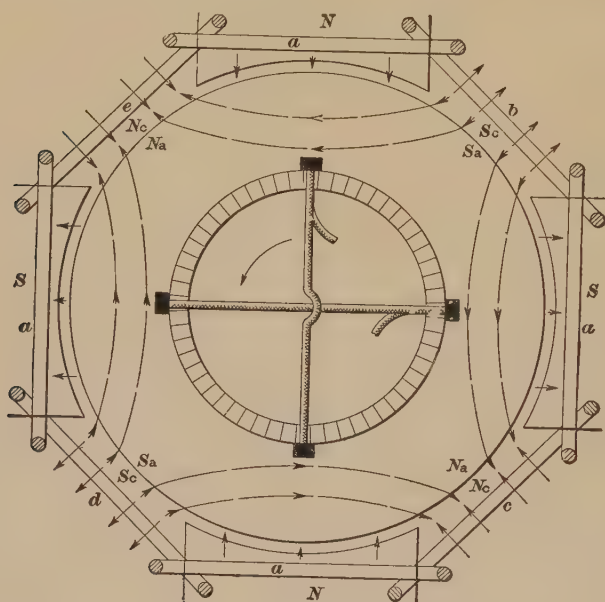


FIG. 3

10. When the current reverses, the polarities at all of the poles shown in Fig. 3 are also reversed. As, in practice, the compensating winding is distributed over the pole faces, and is so connected that the current in the turns of the coils tends to set up in the pole faces and between the pole tips lines of force that directly oppose the lines of force caused by the current in the adjacent armature coils, the inductance of the compensating winding and the armature winding is nearly, but not entirely, neutralized, as is also the distorting effect of the armature current on the field strength.

E.M.F.'s DEVELOPED IN ARMATURE

11. Speed and Transformer E.M.F.'s.—When the armature of an alternating-current series motor is rotating in the magnetic field set up by the main exciting coils, a counter E.M.F. is generated in the armature coils in the same manner as in the armature of a direct-current motor. This E.M.F. will be referred to as the **speed E.M.F.**, because it is due to the rotation of the armature. In an alternating-current motor there is also set up in the armature coils an E.M.F. due to the alternating magnetic flux passing through the pole pieces and armature. This E.M.F. is due to transformer action, and will be referred to as the **transformer E.M.F.** The speed E.M.F. is proportional to the speed; the transformer E.M.F. is proportional to the frequency of the alternating current. The speed E.M.F. is the useful one, as it is the counter E.M.F. of the motor. The effect of the transformer E.M.F. in part of the coils is neutralized by the effect of the same E.M.F. in the remaining coils.

12. Direction of Speed E.M.F.—The relative directions in which the speed E.M.F.'s developed in an armature act are indicated in Fig. 4 by the full-line arrows. A ring-wound armature is shown, as the diagram is thus made more easy to follow than if a regular drum winding were illustrated. Assuming that the polarities of the pole pieces at a given instant are north *N* and south *S* as marked, and the direction of rotation as indicated by the long curved arrow, the directions of the counter E.M.F.'s are away from brushes *b* and *d* and toward brushes *a* and *c*.

13. Direction of Transformer E.M.F.—The direction in which an induced E.M.F. acts round a coil depends on the direction of the lines of force in the coil and whether their number is increasing or diminishing. It may be determined by the following rule:

Rule.—If the effect of the magnetic action is to diminish the number of lines of force that pass through the coil, the E.M.F. will act round the coil in a clockwise direction, as viewed by a

person looking along the magnetic field in the direction of the lines of force. If the effect is to increase the number of lines of force that pass through the coil, the E.M.F. will act round the coil in a counter-clockwise direction, as viewed by a person looking along the magnetic field in the direction of the lines of force.

14. In Fig. 4, the alternating magnetic flux at a given instant is supposed to be increasing in value, and is of the polarity indicated by the letters on the pole pieces. Standing at point *e*,

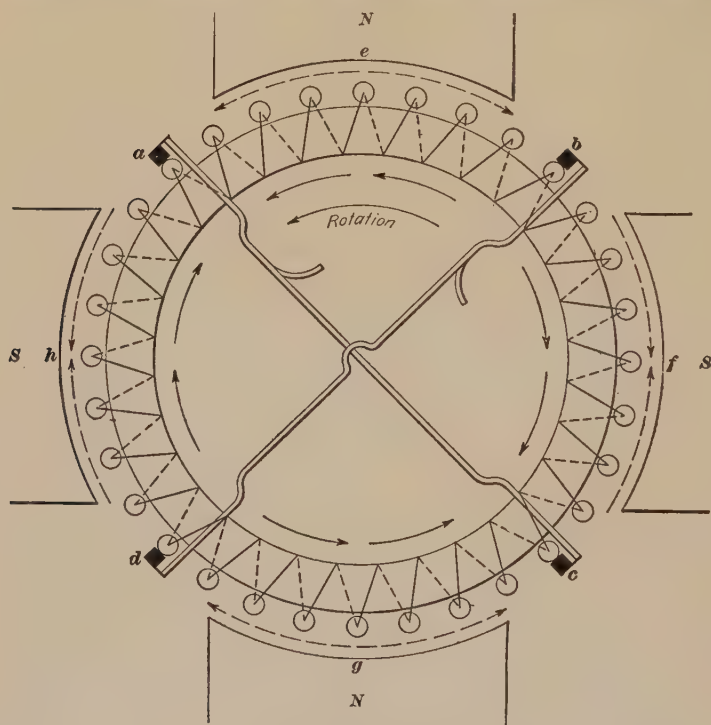


FIG. 4

and looking along the lines of force toward *h*, the increasing magnetic flux will set up an E.M.F. that will tend to send a current round the turns of wire in a counter-clockwise direction ; that is, the transformer E.M.F. is from *e* to *h*. By similar reasoning, the other transformer E.M.F.'s are found to be from *e* to *f*, from *g* to *h*, and from *g* to *f*, as indicated by the long

dotted arrows. In the set of coils between any two brushes, it should be noted that the transformer E.M.F. in one half of the coils is directly opposed by the transformer E.M.F. in the other half of the same set of coils. These E.M.F.'s therefore neutralize each other, and the speed E.M.F. is affected but little, provided the brushes are on the neutral points.

15. E.M.F.'s in Drum Winding.—A developed winding of a parallel-wound four-pole drum armature is shown in Fig. 5. The field magnetic flux is assumed to be increasing in value and of the polarity indicated by the letters *N* and *S*. The directions

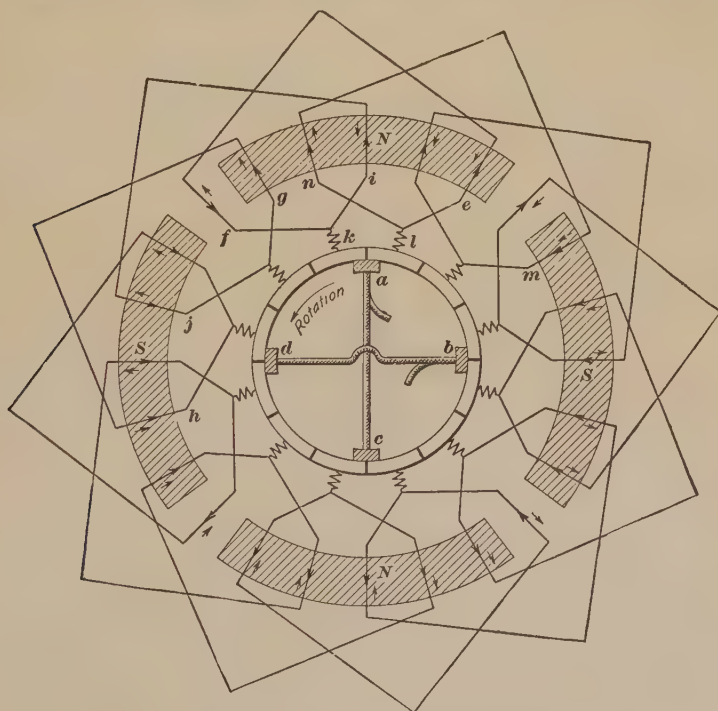


FIG. 5

of the speed or counter E.M.F.'s are indicated by the arrowheads on the conductors. Lines of force are assumed to be coming up through coil *ef* from the north pole below it. The transformer E.M.F. tends to send a current round the coil of such

direction that, if it actually flowed, it would set up lines of force opposite in direction to those emanating from the pole piece. The flow of current in coil ef would thus be clockwise, as indicated by the short arrows near the conductors, and the direction of the lines of force would be downwards through the coil.

16. Where an armature coil is opposite parts of both a north pole and a south pole, the pole having the larger portion of the magnetic flux passing through the coil is assumed to exert the greater influence. For instance, in Fig. 5, coil gh lies partly over a north pole, but mostly over a south pole, and as the lines of force are increasing in value and are passing down through the coil into the south pole, the transformer E.M.F. is in a counter-clockwise direction. This E.M.F. tends to set up a current that will in turn set up lines of force passing up through the coil, these lines being opposite in direction to the main field lines passing into the south pole. It should be noted that in coils ij and gh , which are connected between brush a and brush d , the speed E.M.F. is in a counter-clockwise direction in both coils, but that in coil ij the transformer E.M.F. is clockwise, while in coil gh it is counter-clockwise. The transformer E.M.F.'s thus neutralize each other so far as their effect on the speed E.M.F. is concerned. The same conditions hold true for the other quarters of the winding between brushes a and b , b and c , c and d .

COMMUTATION AND COMMUTATING POLES

17. **Voltages in Short-Circuited Coils.**—When two commutator segments are under a brush at the same time, the coil which is connected between them is short-circuited by the brush. For example, in Fig. 5, coil ef has its ends connected by brush a . During the time that each coil is short-circuited there are two E.M.F.'s set up in it, known as the *reactance voltage* and the *transformer voltage*.

18. **Reactance Voltage.**—At the instant that each coil comes under the brush and is short-circuited, it is carrying the full current which is circulating in the armature winding. As soon

as the coil is short-circuited this current commences to die away, and must pass through zero value and rise to full value in the opposite direction before the coil is disconnected from the brush. Every current-carrying conductor is surrounded by a magnetic field of its own, and as the current changes in value, this magnetic field changes also and cuts the turns of the short-circuited coil, thus setting up an E.M.F. of such a direction as to tend to oppose the change in the current. This E.M.F. is known as the **reactance voltage**.

19. Transformer Voltage.—The short-circuited coil ef , Fig. 5, at the instant shown, is opposite the pole piece N , and as the polarity of the pole piece is periodically changing, an alternating magnetic flux is set up through the coil as it moves past the pole. The coil acts as the secondary of a transformer, of which the field winding on the pole piece N is the primary, and the E.M.F. developed is therefore called the **transformer voltage**. The resultant voltage acting in each coil as it is short-circuited is composed of the reactance and transformer voltages. As the ohmic resistance of the closed circuit is low, a very large current will flow through the coil and cause violent sparking at the brushes when the local circuit is broken if precautions are not taken to prevent it. In order to reduce the short-circuit current, usually only one turn per coil is used, a low frequency of the alternating current is employed, a low value of E.M.F. is applied to the motor terminals, and the magnetic circuits are carefully designed.

20. Resistance Leads.—A method used by some manufacturers to reduce the short-circuit current is to connect the junctions of the coils to the commutator segments with leads of resistance metal, as shown at k, l , Fig. 5. The resistance of these leads k, l prevents an excessive current from flowing through the local circuit composed of the coil ef , the leads k, l , the two commutator bars, and the brush a . The leads carry current only when the commutator bars to which they are connected are in contact with the brushes, as the armature windings form a closed circuit independent of the leads. The loss occasioned by the resistance of the few leads in circuit at the brushes at any time

is slight. In small alternating-current armatures, such as are used in motors for driving air compressors, no resistance leads need be used, as the brushes usually have sufficient resistance to limit the short-circuit current.

21. In railway motors of ordinary size, the resistance leads are usually tapped to the armature winding at the rear end of the core and brought to the commutator segments through the same slots as the main winding. In some of the large locomotive motor armatures, in order to secure a greater length, the leads are tapped to the armature winding at the front end of the core, carried to the rear end, doubled back to the front end, and then connected to the commutator. In case a short circuit should occur in the field windings or in the armature, the transformer voltage set up by the alternating magnetic flux will cause an excessive current to flow through the short-circuited section and perhaps result in a burnout.

22. Use of Commutating Poles.—A method of reducing sparking at the brushes of a railway motor, which is very successful in practice, is to induce in the short-circuited coil a voltage which is equal and opposite to the resultant E.M.F. due to the reactance and transformer actions. This is effected by providing the motor with small **commutating poles** situated between the main poles. The windings of these commutating poles are supplied with current of such strength and phase that, when the short-circuited coil revolves in the field set up by the commutating-pole windings, the voltage generated in it neutralizes the reactance and transformer voltages almost completely. In order that the current in the windings of the commutating poles shall be of the correct strength and phase, these windings are connected in many ways. They are in some cases connected in shunt with the motor, either by themselves or in combination with resistances or choking coils; in other cases they are fed by a special transformer or autotransformer connected in parallel with the armature. In some types of motors, both resistance leads in the armature and commutating poles have been used to reduce sparking.

23. Connections of Commutating-Pole Windings.—Some of the methods of connecting the windings of the commutating

poles of alternating-current series motors are shown in Fig. 6. In each case the main field winding *a* is connected in series with the armature *c*, but the compensating winding *b* and the commutating-pole winding *d* have various connections. In the arrangement shown at (a) the commutating-pole winding *d* is connected in parallel with a non-inductive resistance *e*. The field set up by the current flowing through winding *d* will be

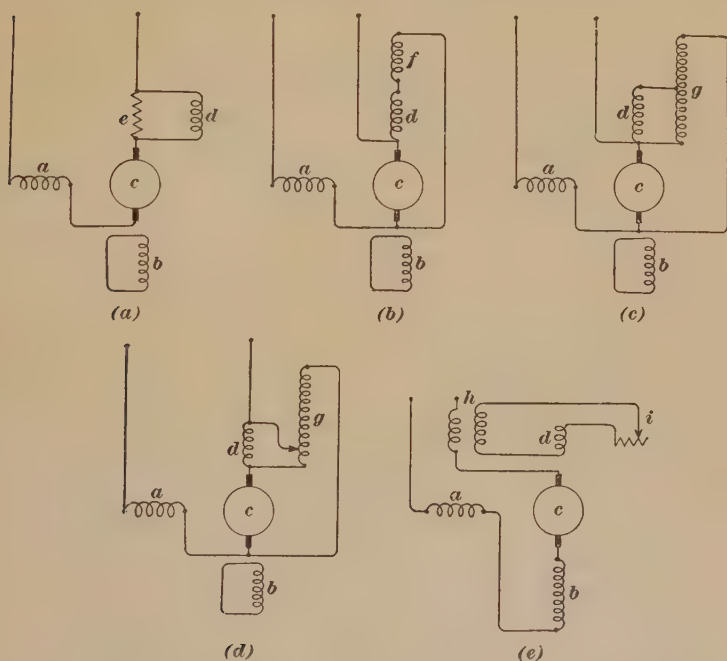


FIG. 6

nearly 90° out of phase with the current in the main circuit of the motor, and will therefore have the proper phase relation to neutralize the transformer voltage in the armature coils short-circuited by the brushes.

24. The arrangement of the various windings of an alternating-current series motor shown in Fig. 6 (b) has the advantage of avoiding a resistance in series with the motor. The commutating winding *d* is connected in series with a choking

coil f , and the two are connected across the terminals of the armature c . Owing to the inductive effect of both windings d and f the current through them, and consequently the flux set up by winding d , will have such a phase relation with the main current as to give a good commutating field.

In Fig. 6 (*c*) the commutating-pole winding d is connected across half the winding of an autotransformer g , which is joined in parallel with the armature c . This arrangement gives practically the same effect as that shown at (*b*). In the arrangement shown in view (*d*) the commutating-pole winding d is joined in series with the motor, and in addition is connected to an autotransformer g which is in parallel with the armature. The phase relation of the current in winding d to the main current may be varied by changing the connection to the autotransformer, so that it is fairly easy to adjust the commutating field for any given conditions.

25. A method of exciting the commutating-pole winding d from a series or current transformer h is shown in Fig. 6 (*e*). Regulation of the strength of the commutating field is made by means of an adjustable non-inductive resistance i . The compensating winding b is connected in series with the motor instead of being short-circuited, as shown in the arrangements previously described. The effect obtained is essentially the same with either method of connection of the compensation winding.

PHASE RELATIONS OF VOLTAGES AND CURRENT

26. **Voltage in Main Field Coil.**—When an alternating-current motor is connected to the mains, the main field winding acts as a choking coil, and has generated in it a counter E.M.F. due to the inductance, which introduces into the alternating-current motor a voltage that is not present in the direct-current motor, and increases the total voltage required for the operation of the motor. As the field coil, armature, and compensating coil are in series, the voltages across the several sections of the winding may be considered as making different phase angles with the current flowing in series through the whole winding.

In such a case, the total voltage will not be the numerical sum of the several voltages, as the difference in phase relation must be considered.

27. Vector Diagram.—The total voltage across the terminals of the motor may be determined by the aid of a vector diagram similar to Fig. 7. When two forces acting in different directions

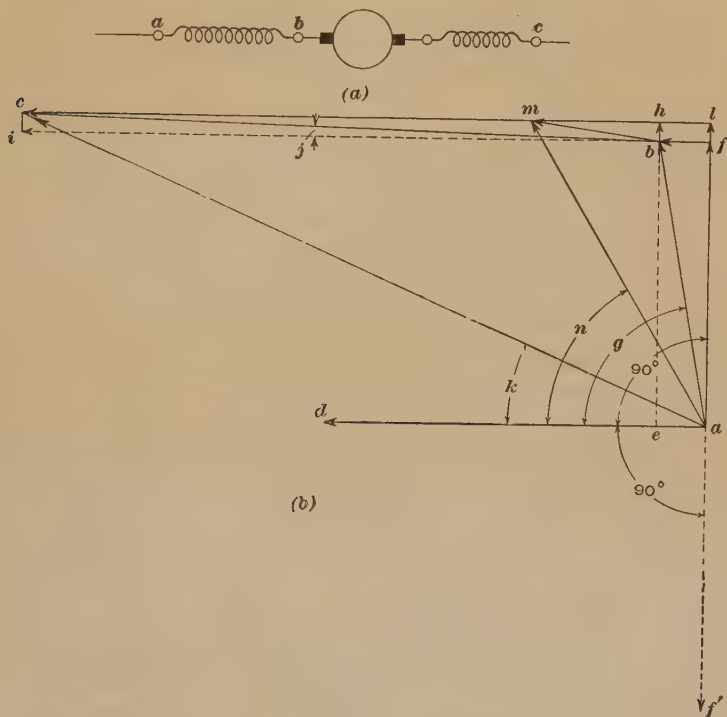


FIG. 7

are represented by the lengths and directions of two joined lines, the force in one line acting from its free end toward the junction of the two lines, and the force in the other line acting from the junction toward its free end, the value and direction of the force necessary to balance the combined effects of the two forces are indicated by the length and the direction of the line connecting the free ends of the two lines. The direction

of this force is taken as opposing the general direction of the forces in the two original lines, which constitute two sides of the triangle of forces thus formed. In Fig. 7 (*a*) is shown the motor circuit, and in (*b*) the corresponding voltage diagram. The sketches are so lettered that line *ab* in view (*b*) represents the voltage across the field coil *ab* in view (*a*); line *bc* in (*b*), the voltage, under running conditions, across the armature and compensating coil *bc* in (*a*); and the resultant line *ac*, in view (*b*), represents the total voltage across the motor terminals *ac* in view (*a*).

28. The directions of the current and voltages are indicated by arrowheads. The value of the current *ad*, Fig. 7 (*b*), is laid off on the horizontal line through *a*. As the field coil has inductance, the voltage *ab* required to drive the current through the field coils is the resultant of two components, one component *af* necessary to overcome the counter E.M.F. due to inductance of the coil, and the other *fb*, or *ae*, necessary to force the current against the ohmic resistance of the coil. The E.M.F. due to inductance lags 90° behind the current, as shown at *af'*, so that the voltage *af* to overcome it is 90° in advance of the current. The voltage *ae* to overcome the ohmic resistance and supply the losses is in phase with the current. It should be noted that *fb* is short in comparison with *af*; therefore the angle of lag *g* of the current *ad* behind the E.M.F. *ab*, applied to the field coil, is nearly 90° .

29. **Voltage Across Armature and Compensating Coil.**—There is little inductance in the combined armature and compensating coil of a series alternating-current motor, as is shown by the line *bh*, Fig. 7, which represents the reactance drop. Under running conditions the energy component *hc* of the applied voltage is large, since it represents the pressure *hm* necessary to overcome the drops in the armature and compensating coils due to their ohmic resistances and the voltage *mc* required to balance the speed E.M.F. The speed E.M.F., which is in phase with the current, multiplied by the current gives the electrical power transformed into mechanical power. The resultant of *bh* and *hc* represents the voltage applied to the combined armature

and compensating coil, and is the diagonal bc of the parallelogram $b h c i$. The applied voltage will be nearly in phase with the current, as shown by the small angle of lag j . The direction of the current is indicated by the line bi parallel to ad .

30. Running Voltage.—The resultant ac , Fig. 7, of the voltage ab across the field windings and the voltage bc across the armature and compensating coil is the voltage applied to the motor when running, and is found by drawing a line joining the points a and c . The direction of this voltage is from a to c , as indicated by the arrowhead, and the current ad lags behind pressure ac by the angle k . In the triangle of forces abc , the general direction of the arrowheads on sides ab and bc is counter-clockwise, while the arrowhead on ac indicates a clockwise direction round the triangle. The running voltage ac may also be considered as the resultant of the total inductive component of the voltage $al = af + bh$ combined with the total energy component $lc = fb + hc$.

31. Starting Voltage.—If the motor is starting and the terminal E.M.F. is reduced so that the current through the motor windings is the same as the running current, the lines fb , af , bh , and hm , Fig. 7, representing, respectively, the E.M.F.'s necessary to overcome the resistance and reactance drops of the field coils and the combined armature and compensating coils, may remain practically unchanged. The energy component hm of the combined armature and compensating coil is now small. Since the developed power at starting is inconsiderable, this component represents the voltage necessary to force the current through the ohmic resistance of the armature and compensating coil. The resultant pressure bm represents the voltage across the armature and compensating winding bc , Fig. 7 (a), under starting conditions. The line ab , Fig. 7 (b), representing the voltage drop across the field winding remains unchanged, as the current value is assumed to be the same as under running conditions. The starting voltage am is the resultant of ab and bm , and represents approximately the E.M.F. which should be applied to the motor terminals when starting in order to keep the current down to the value represented by ad .

32. Power Factor.—The angle of lag k , Fig. 7, between the running voltage and the current is much less than the angle of lag n between the starting voltage and the current. Therefore, the current in the first case is more nearly in phase with the E.M.F., and the power factor under running conditions is much higher than under starting conditions. If the inductance of the armature had not been neutralized by the action of the compensating coil, the power factor would have been lower under both starting and running conditions. At starting, the counter E.M.F. due to the field-coil inductance has a much greater effect on the total motor voltage than under running conditions, due to the inductive component not changing greatly, while a great change takes place in the energy component. With alternating current, the starting voltage is a larger proportion of the final running voltage than when direct current is used on the same motor and under similar conditions.

CHARACTERISTICS OF SERIES ALTERNATING-CURRENT MOTOR

33. Speed.—The speed at which the armature of an alternating-current series motor rotates depends on the voltage applied to the motor terminals and on the load. In this respect the motor resembles its direct-current counterpart, and the speed of the motor is readily regulated by varying the applied voltage. The alternating-current motor possesses the advantage, however, that the voltage applied to the motor terminals can be varied by means of a transformer, without waste of energy in resistances. The maximum pressure applied to a single motor seldom exceeds 350 volts, as it is difficult to design satisfactory motors for a higher voltage.

34. Characteristic Curves.—The characteristic curves of a 210-horsepower railway motor for various terminal voltages are given in Fig. 8. The curves a to g , view (a), show the speed, in miles per hour, of the locomotive carrying the motor, at voltages ranging from 150 to 320. They are plotted with the current taken by the motor as abscissæ. The efficiency of the

motor and its gearing at various voltages and currents is shown by curves *h* to *n*. The tractive effort exerted by the motor at

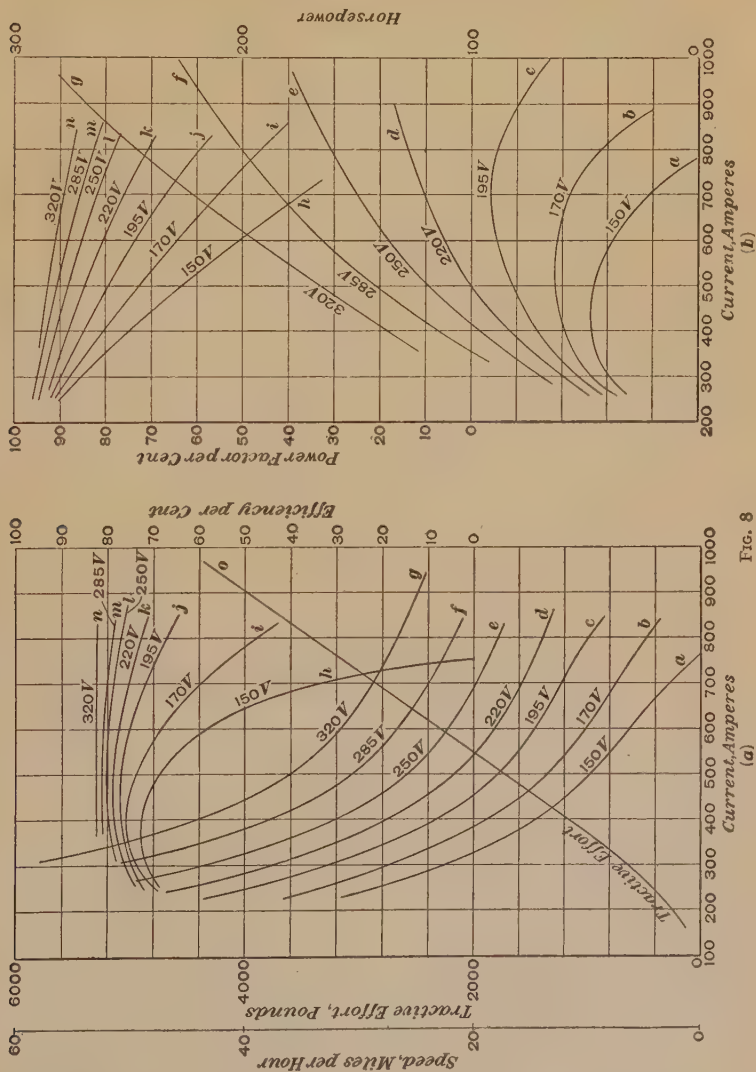


Fig. 8

various currents is given by curve *o*. The curves *a* to *g* in view (b) show the horsepower developed by the motor at various

voltages and currents, and the curves *h* to *n* show the power factor under similar conditions.

35. Operation on Direct Current.—When the windings of the compensating coil are connected in series with the armature and main field windings, an alternating-current series motor can be operated from a direct-current supply. All the features introduced to prevent sparking when running on alternating current are operative when the motor is running on direct current, and therefore, as the tendency to sparking is much less in the latter case the commutation is excellent. Owing to the fact that there is no E.M.F. required to overcome the reactance of the field windings when the motor is working on direct current, the whole of the counter E.M.F. has to be produced by the rotation of the armature. The speed of the motor is therefore higher with a given voltage on a direct-current supply than it is with the same voltage on an alternating-current supply if the field connections remain the same in the two cases. The losses when working on direct current are also less, and there is no power factor to be considered, so that the same output can be obtained from the motor on direct current with a smaller current input.

36. The performance curves of the same motor when run on alternating current at a frequency of 25 cycles per second, and on direct current, are shown in Fig. 9 (*a*) and (*b*), respectively. The applied voltage in each case is 250, and it will be noted that, when operating with alternating current, the highest net efficiency is 80 per cent., and when operating with direct current, the efficiency rises to 83.5 per cent. The speed curves show that for equal currents the speed is higher when the motor is operated on alternating current than when operated on direct current. This is due to the fact that for alternating-current operation the field coils on the various poles are connected in parallel, while for direct-current operation the coils are connected in series, the fields in each case being in series with the armature. With the series connection of the windings, the field flux is much greater than with the parallel connection, and hence the speed is lower.

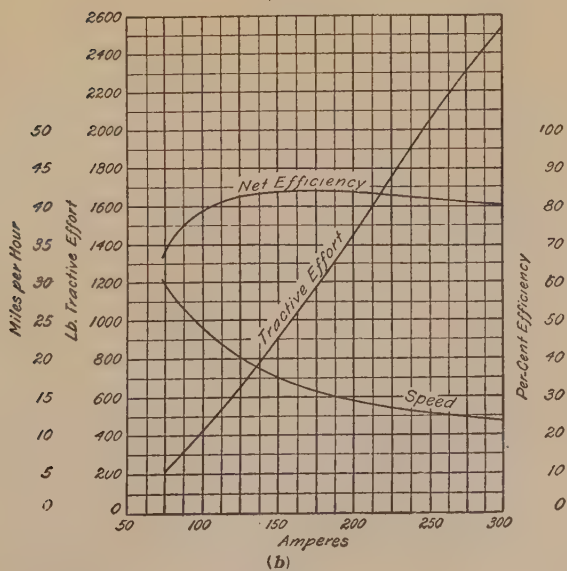
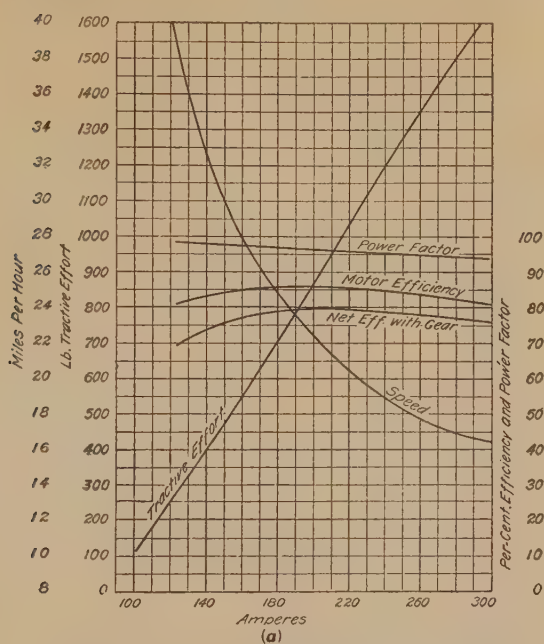


FIG. 9

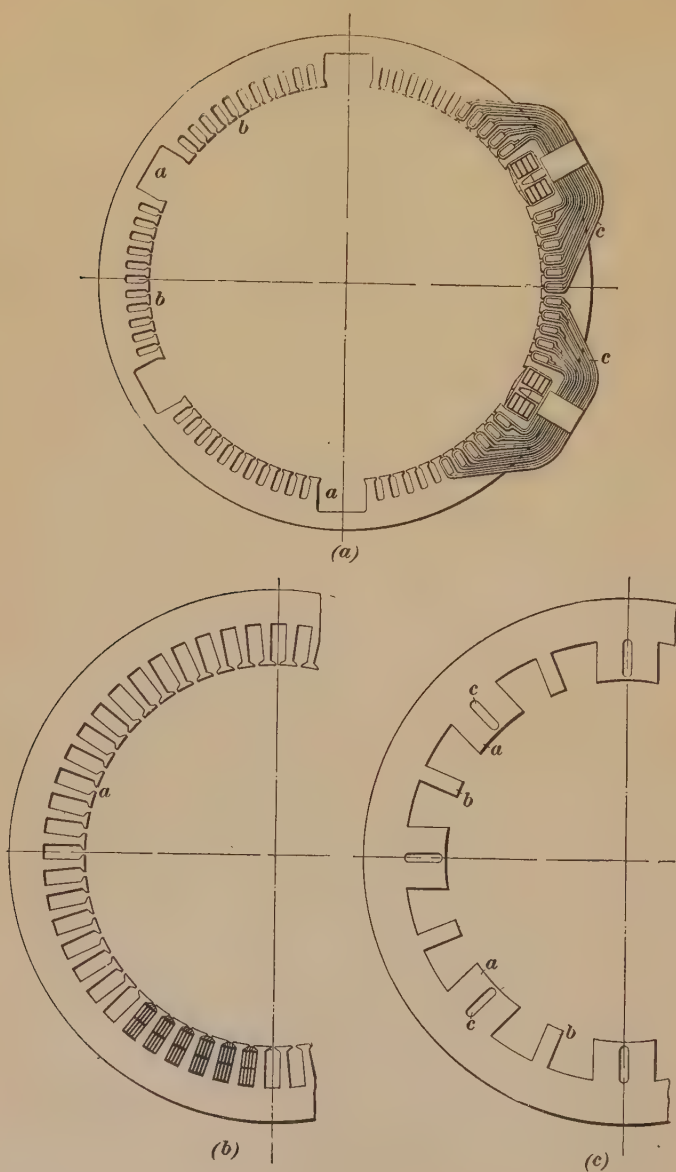


FIG. 10

CONSTRUCTION OF ALTERNATING-CURRENT SERIES MOTOR

37. Field, or Stator.—Several types of construction have been used for the field, or stator, of alternating-current series motors. One of the most common types is built up of stampings such as are shown in Fig. 10 (*a*). The main field coils are placed in the large slots *a*, the polar faces being furnished with a number of slots *b* in which are placed the compensating coils, the end connections of which are shown at *c*. Commutating poles are not used with this type of construction.

38. A stamping for a type of motor which is provided with commutating poles is shown in Fig. 10 (*b*). The stator is furnished with a number of equally spaced slots *a*, in which the windings for the main field, compensating coil, and commutating poles are placed. Each coil of the commutating-pole winding encircles only a single tooth, which is thus made the commutating pole. The centres of the main field coil and compensating coil are spaced one-half a pole pitch apart, and the centre of the commutating-pole winding coincides with that of the compensating coil. The stator laminations in both types of motor are held between end plates in a housing, in exactly the same manner as the laminations of the stator of an induction motor.

A type of field which was used when single-phase series motors were first introduced is shown in view (*c*). In this case both the main and commutating poles were formed by actual polar projections, shown at *a* and *b*, respectively, as in a direct-current machine. The compensating winding was placed in one or more slots *c* in the centres of the main polar projections. This type of construction has now been superseded by the smooth-core construction shown in view (*b*).

39. Armature.—The armatures of alternating-current series motors only differ from those used for direct-current motors and generators in that the armature conductors are often connected to the commutator segments by high-resistance leads. In some cases these leads are situated in the space between the end of the armature and the commutator. In others, the armature conductors are tapped by the high-resistance leads at the end

of the armature farthest from the commutator, and the resistance leads are taken to the commutator through the same

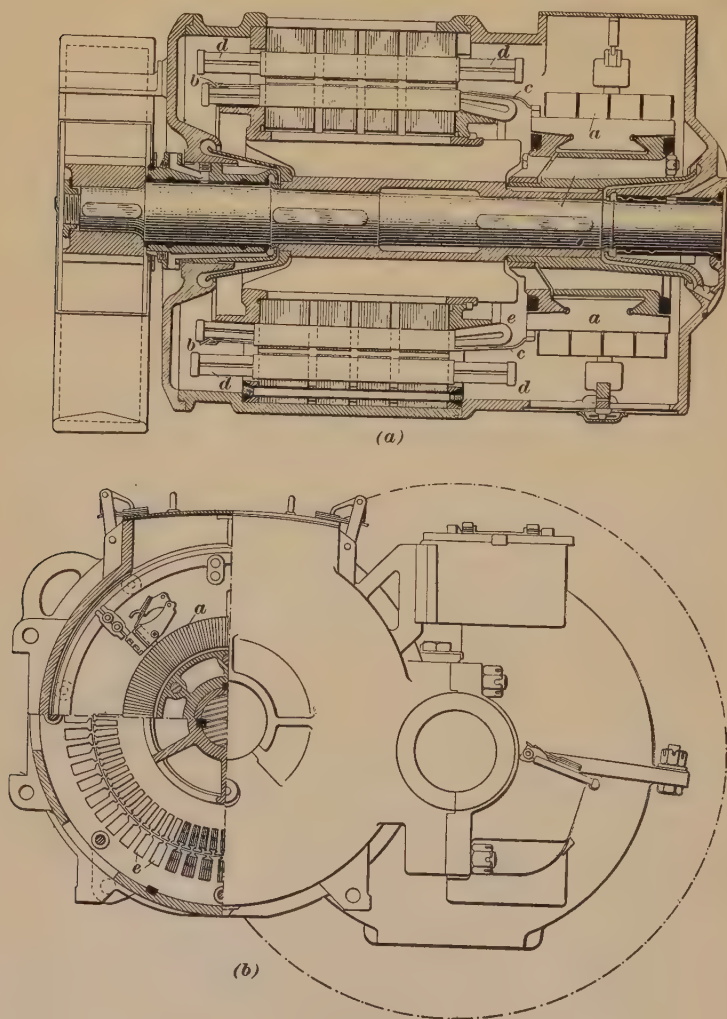


FIG. 11

slots as the armature conductors, or through separate holes in the armature core below the main slots. This enables longer

resistance leads to be used, and thus increases the resistance in circuit with the short-circuited coil during commutation. In Fig. 11 is shown the construction of a 225-horsepower railway motor, view (a) being a section parallel to the shaft, and (b) an end view and part section. The commutator *a* is connected to the armature conductors at the point *b* by the resistance leads *c*, which are placed above the ordinary conductors in the main armature slots. These resistance leads carry current only when they are in the commutating field, and therefore have practically no effect on the torque of the motor. The field windings *d* are placed in a number of equally spaced slots *e*. The bearings in this motor, as in almost all railway motors, project under the armature spider at one end and the commutator spider at the other, thus economizing space and increasing the rigidity of the armature.

40. Suspension and Driving Arrangements of Motors.—Single-phase motors are suspended and coupled up to the wheels in the same way as direct-current or three-phase motors. Fig. 12 shows

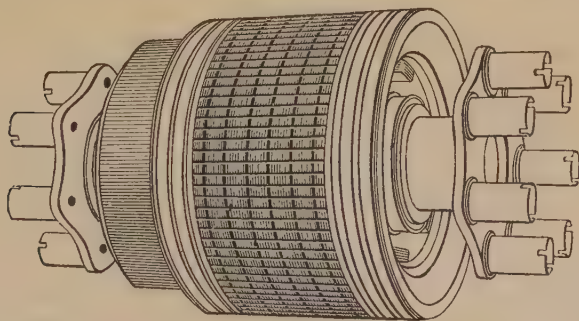


FIG. 12

the armature of a Westinghouse gearless motor for coupling direct to the track wheels. The armature is not placed directly on a shaft, but is built up on a hollow cylinder, or sleeve, through which the car axle passes. There is a clearance of about $\frac{5}{8}$ inch between the axle and the inside of the sleeve. The motor frame rests on bearings located near the rear of the armature core and the front end of the commutator spider. At each end of the

sleeve is a flange, from which project seven round hollow pins, as shown.

41. The pins shown in Fig. 12 fit into corresponding pockets in the hubs of the driving wheels, as shown in Fig. 13, which also shows the relative positions of a motor and its driving wheels. Coiled springs placed between bushes on the driving pins and bushes in the pockets take up the vibrations of the truck. The spring wound on the bush of each driving pin is so

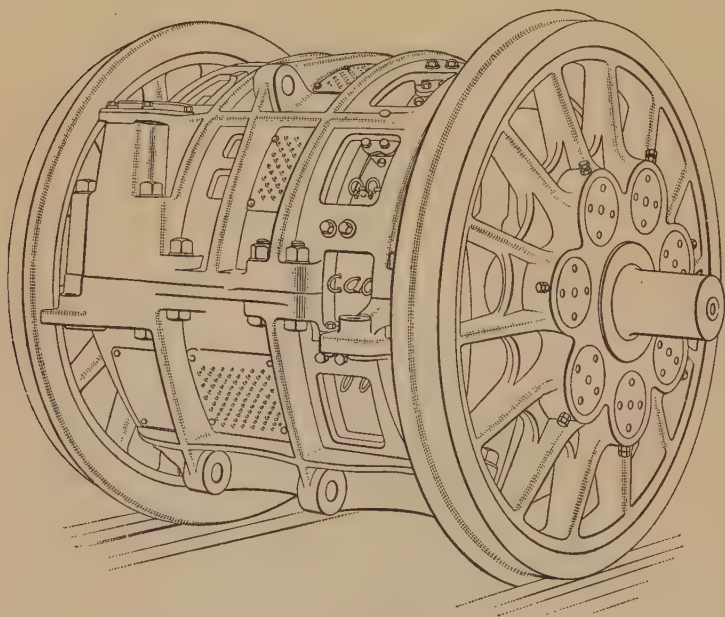


FIG. 13

constructed that it holds the pin nearly central in the recess ; the end play of the motor is taken up by coiled springs, within the hollow driving pins, which press against covers in the outer ends of the pocket in the wheels. The entire weight of the motor is normally carried on springs supported from a steel frame surrounding the motor and resting on journal-boxes on the truck frame. Each motor has a normal rating of 250 horsepower for 1 hour, and a capacity of 200 horsepower for continuous working.

COMPENSATED REPULSION MOTOR

THEORY OF OPERATION

42. Points of Difference From Series Motor.—The compensated repulsion motor is so called because it is similar in principle to the ordinary repulsion motor, and because under some conditions its inductance is compensated for, so that it operates at unity power factor. In the series motor, current is conveyed to the armature by conduction, that is, the armature is connected by means of the brush leads in series with the field windings. In the compensated repulsion motor of the Winter-Eichberg type, on the other hand, current is induced in the armature coils by mutual induction from the field windings and the main motor field is produced by another current flowing in the armature superposed on the induced current.

43. Method of Connection.—The various elements of the motor in its simplest form are shown in Fig. 14. When current from the line passes through the single winding *a* on the stator, it produces a magnetic field in the direction of the arrow. This magnetic field passes through the armature *b* and, as it is an alternating field, sets up an alternating E.M.F. in the armature coils through which it passes. The coils of the armature *b* are connected in the ordinary manner to a commutator on which there are two sets of brushes *d*, *d'* and *e*, *e'*. One set *d*, *d'*, called the **exciting brushes**, is joined in series with the stator winding; the brushes of the **short-circuited set** *e*, *e'* are connected together by the connection *c*. As in the series motor, there are both speed and transformer E.M.F.'s in the armature winding.

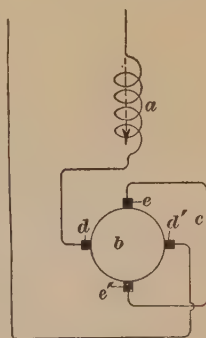


FIG. 14

The E.M.F. in any single coil will be proportional to the rate of change of the total flux passing through that coil, and as this

flux is in a definite direction, as indicated by the arrow, the E.M.F. in any particular coil will depend on the position of that coil.

44. **Directions of Transformer E.M.F.'s.**—The arrangement for a simple two-pole field and a ring-wound armature is shown in Fig. 15, the commutator being omitted for the sake of simplicity. At the instant under consideration, the polarity of the field is as indicated by the letters *N* and *S* due to current supplied from mains connected to terminals *h* and *g*, and is increasing in strength; the motor is supposed to be standing still. The coils *a*, *a'* have the field set up by the resultant of the stator ampere-turns and the armature ampere-turns due to the induced current, passing through them, and therefore have induced

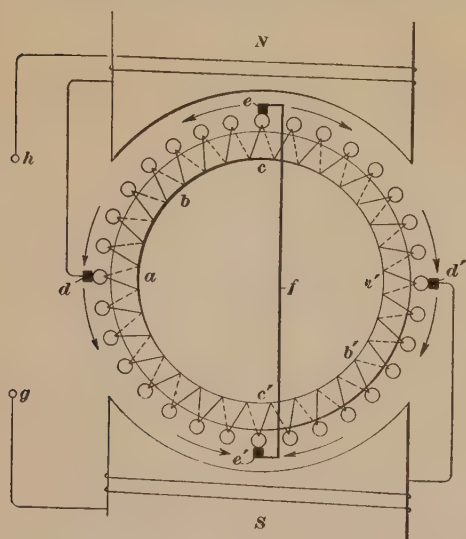


FIG. 15

in them the full value of the transformer E.M.F. The coils *b*, *b'* are only cut by a fraction of the total flux, and therefore have only a fraction of the full E.M.F. induced in them, while coils *c*, *c'*, which lie in the same plane as the field, are not cut at all and have no E.M.F. By applying the rule in Art. 13, it will be found that the directions of the transformer E.M.F.'s are as

shown by the curved arrows. There is no E.M.F. due to transformer action across the brushes *d*, *d'*, because the effects of the sections of the winding between these brushes neutralize one another. The full transformer E.M.F. is, however, obtained across the brushes *e*, *e'*.

45. As the full transformer E.M.F. is acting across the short-circuited brushes *e*, *e'*, Fig. 15, a current will be produced in

the closed circuit composed of the armature coils, the two brushes e , e' , and the connection f . A simple and useful way of considering this point is to regard an armature with its commutator as capable of producing a magnetic field, the axis of which is along the line joining the brushes through which the armature current passes. Thus, a current passing through the short-circuited brushes e , e' will tend to produce a magnetic field with a vertical axis, and a current through the exciting brushes d , d' will tend to produce a magnetic field with a horizontal axis. Two currents entering the armature simultaneously by the two brush sets will produce a resultant field which may be considered as being made up of two independent magnetic fields along the two perpendicular axes, the strength of each being proportional to the current producing it, neglecting magnetic saturation of the iron parts of the motor. Considering the armature in this way, the closed circuit completed by the brushes e , e' and the connection f may be regarded as the secondary winding of a transformer of which the field coils are the primary, and the *vector diagram* showing the relations of the magnetic field, the transformer E.M.F., and the currents in these two circuits can be drawn exactly in the same way as for a static transformer, provided the motor is not running.

46. Production of Torque.—In Fig. 15 it is shown that the induced current in the armature coils between brushes e and d is in an opposite direction to that between brushes e and d' . Similarly, the currents in the circuits $e' d$ and $e' d'$ are in opposite directions. Hence, there can be no resultant torque due to the interaction between the currents in the armature and the magnetic field produced by the stator coil, as the force produced by the current in any one conductor is neutralized by the force due to the current in another conductor. If, however, a magnetic field is provided, the axis of which is at right angles to the field due to the stator coil, there will be a definite torque due to the action of this field on the armature conductors carrying current if this field and the armature current are not 90° out of phase. This is the actual method whereby the torque of the compensated repulsion motor is produced, the magnetic field

which gives the torque reaction being provided by means of the current, called the exciting current, entering and leaving the armature by the exciting brushes d, d' .

To summarize, a current which enters and leaves by means of the short-circuited brushes e, e' is induced in the armature, and a magnetic field is produced by an exciting current entering and leaving the armature through the exciting brushes d, d' , and this field reacting on the induced armature current produces the torque of the motor. The exciting field, with an axis through d, d' , which is set up by the exciting current also gives rise to transformer and speed E.M.F.'s. These manifest themselves at 90 electrical degrees to the transformer and speed E.M.F.'s due to the first field; that is, the transformer E.M.F. due to the exciting field is operative at the exciting brushes d, d' , and the speed E.M.F. due to the exciting field is at the short-circuited brushes e, e' .

VOLTAGE AND CURRENT RELATIONS IN COMPENSATED REPULSION MOTOR

47. Voltage and Current Relations at Starting.—The phase relations of the currents and pressures in the windings of a compensated repulsion motor at starting are given by the vector diagram, Fig. 16. The

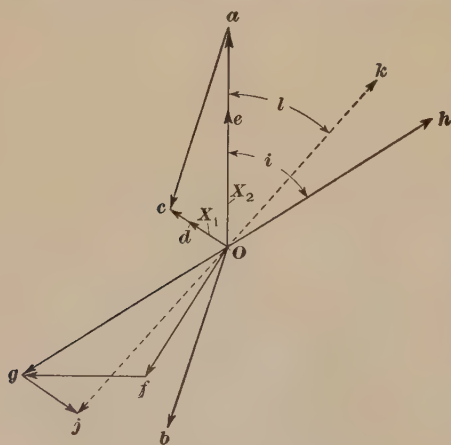


FIG. 16

windings. The primary current therefore sets up a magnetic

compensated repulsion motor at starting are given by the vector diagram, Fig. 16. The current in the stator windings, that is, the primary current, is represented by the line Oa . This primary current also flows through the armature windings, by means of the exciting brushes, and acts as an exciting current in the armature

field X_2 , which is represented on the diagram by the line Oe . A large induced current circulates in the armature windings through the short-circuited brushes and is nearly opposite in phase to the primary current Oa , so that the line Ob represents the induced or secondary current. The magnetic field X_1 , which causes the secondary current Ob to flow, is due to the resultant ampere-turns of the primary current in the stator coil and the secondary current in the armature. The field is represented on the diagram by the line Od , and is produced by the equivalent current Oc , which is the resultant of the primary current Oa and the secondary current Ob .

48. The alternation of the field X_1 , Fig. 16, sets up an induced or transformer E.M.F. E_1 in the stator coil and this E.M.F. is represented by line Of at right angles to Od . The field X_1 also produces a transformer E.M.F. in the armature windings between the short-circuited brushes. This E.M.F. is in phase with the E.M.F. E_1 and causes the flow of the secondary current Ob . The alternation of the field X_2 induces an E.M.F. E_2 between the exciting brushes of the armature. The E.M.F. E_2 is represented on the diagram by the line fg , at right angles to Oe , and tends to cause the primary current Oa to lag behind the impressed E.M.F., Oh . The impressed E.M.F. must be equal and opposite to the resultant Og of Of and fg .

49. **Effect of Speed E.M.F.'s When Running.**—When the armature of a compensated repulsion motor begins to rotate, a speed E.M.F. due to the conductors cutting the lines of force of the exciting field X_2 , Fig. 16, is developed between the short-circuited brushes. This E.M.F. is in phase with the field X_2 and more or less directly opposes the transformer E.M.F. which causes the secondary current to flow, the resultant voltage being just sufficient to force the secondary current through the circuit against the impedance of the windings. A speed E.M.F. is also generated in the armature by the conductors cutting the flux of field X_1 . This E.M.F. is between the exciting brushes and is therefore in the primary circuit of the motor. The speed E.M.F. is in phase with the field X_1 and is represented on the diagram by the line gj , which shows that the E.M.F. is acting

from g toward j , thus more or less completely neutralizing the transformer E.M.F. fg . The effect of this neutralizing action is to bring the resultant pressure from line Og to Oj . The impressed pressure will thus be brought from the position Oh to the position Ok . The angle of lag of the current Oa is reduced from the angle i to the angle l , thus improving the power factor of the motor. As the speed is increased the speed E.M.F.'s will increase, and at a certain speed the impressed pressure may be brought into phase with the primary current and the power factor made unity. If the speed is further increased a leading current may be obtained, but when this condition is obtained there is usually a certain amount of sparking. The motor is commonly run at a speed somewhat less than that required to give unity power factor.

COMMUTATION OF REPULSION MOTOR

50. Commutation at Brushes Carrying Induced Armature Current.—The commutation at the short-circuited brushes carrying the induced current must be considered separately from the commutation at the brushes which carry the exciting current. In the coils short-circuited by the main brushes there is a speed E.M.F. due to the conductors moving in the main field of the motor, a transformer E.M.F. due to the alternation of the exciting field set up by the armature, and a reactance voltage due to the reversal of the induced current as the commutator segments pass under the brushes. The resultant E.M.F. must be kept small or partially neutralized by a commutating field of the proper strength and direction in order to avoid violent sparking. The resultant E.M.F. cannot easily be completely neutralized, because the speed E.M.F. varies with the speed and the reactance voltage varies with both speed and load, while the commutating field is usually made to vary only with the load.

51. Commutation at Brushes Carrying Exciting Current.—As the exciting current supplied to the armature of a compensated repulsion motor is small compared with the induced current, there is comparatively little trouble due to sparking. The transformer E.M.F. in the short-circuited coil is not excessive, as the

field set up by the stator winding is much less than the field due to the exciting current. The speed E.M.F. due to the coils short-circuited by the exciting brushes cutting lines of force of the exciting field may be fairly large, but is more or less completely neutralized by the transformer E.M.F. due to the stator field. In practice, no difficulty due to sparking at the exciting brushes has been encountered.

SPEED REGULATION OF REPULSION MOTOR

52. **Theory of Speed Variation.**—The compensated repulsion motor may be controlled in the same way as a single-phase series motor, that is, by varying the applied terminal voltage by means of a variable ratio transformer, or in any other convenient manner. In practice, however, it is usual to employ a series transformer to supply the magnetizing current for the armature, as shown in Fig. 17. The stator coil *a* is connected to the primary winding *f* of a series transformer, the secondary *g* of which is connected to the brushes *d*, *d'*. The series transformer can be made with

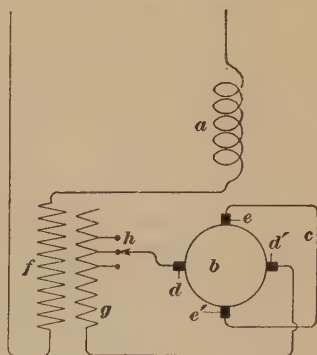


FIG. 17

any desired ratio between the primary and secondary turns, or it may be made with a variable ratio by providing the secondary with a number of tapings *h*. At starting, the pressure across the exciting brushes *d*, *d'* is made high in comparison with the pressure across the motor terminals. A strong exciting field will be produced, and therefore a low speed will give a speed E.M.F. great enough to limit the induced current due to the main field in the circuit *e e e'*. The speed of the motor may be increased by increasing the E.M.F. applied to the main terminals. This increase in applied E.M.F. will cause the main current and therefore the induced current to increase. If the exciting field remains constant, the torque will increase and thus increase the speed. If the exciting field is weakened, the speed E.M.F. opposing the flow of induced current will be decreased and the

induced current will increase until the speed E.M.F. again comes up to its normal value due to increase of speed.

53. Arrangement of Connections for Speed Control.—In the most modern arrangements an autotransformer *d*, Fig. 18, is

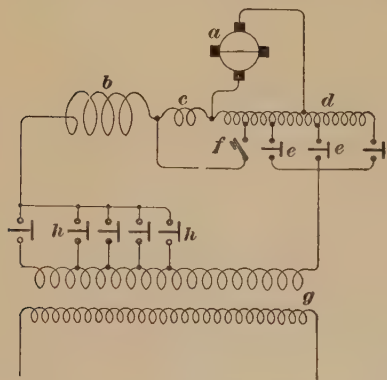


FIG. 18

used to supply the exciting current to the armature *a*. The exciting current can be adjusted to suit the running or starting conditions by closing different contactors *e*. The main field *b* and the commutating field *c* are connected in series, but the phase relation of the commutating field may be changed to suit the usual running conditions by closing contactor *f*. The pressure applied to the motor

is controlled by contactors *h* connected to consecutive tappings on the secondary of the main transformer *g*. The primary of the transformer *g* is supplied with current at high pressure from the trolley wire, and this is stepped down to a pressure suitable for the motors. The highest pressure applied to the motor terminals is about 750 volts.

54. Theoretically, there is no reason why the stator winding of a compensated repulsion motor should not be wound for direct connection to the high-tension trolley wire, the only current transformed being that required for the exciting circuit on the armature. In practice, however, on account of the increased cost of upkeep due to having a high voltage on the motors, it is usual to install a step-down transformer, as shown in Fig. 18.

CHARACTERISTIC CURVES OF REPULSION MOTORS

55. Tractive-Effort, Speed, Efficiency, and Power-Factor Curves.—The compensated repulsion motor fulfils the requirement of a good traction motor in that it is capable of giving a

large starting torque. Its characteristic curves much resemble those of the series motor, in that the torque increases and the speed decreases rapidly as the load becomes greater. In Fig. 19 are shown the curves for a 6,000-volt 25-cycle motor, the control of which is effected by varying the transformation ratio of the

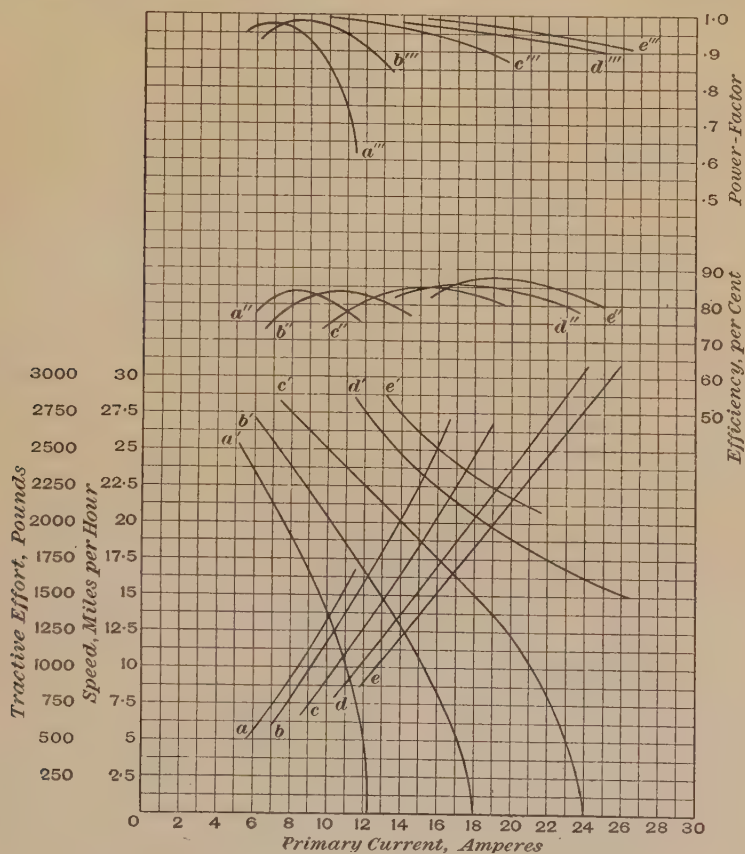


FIG. 19

step-down transformer in the supply circuit. Curves *a*, *b*, *c*, *d*, *e* show how the tractive effort, in pounds, exerted by the locomotive carrying the motor varies with the primary current for different pressures applied to the motor terminals. The corresponding curves of speed, in miles per hour, are shown

at a', b', c', d', e' . The efficiencies of the motor at different loads and with the various applied pressures are given by the curves a'', b'', c'', d'', e'' , the loss due to the exciting transformer being included with the motor losses. The way in which the power factor varies with the load for various ratios is shown by the curves $a''', b''', c''', d''', e'''$; these show that, by changing

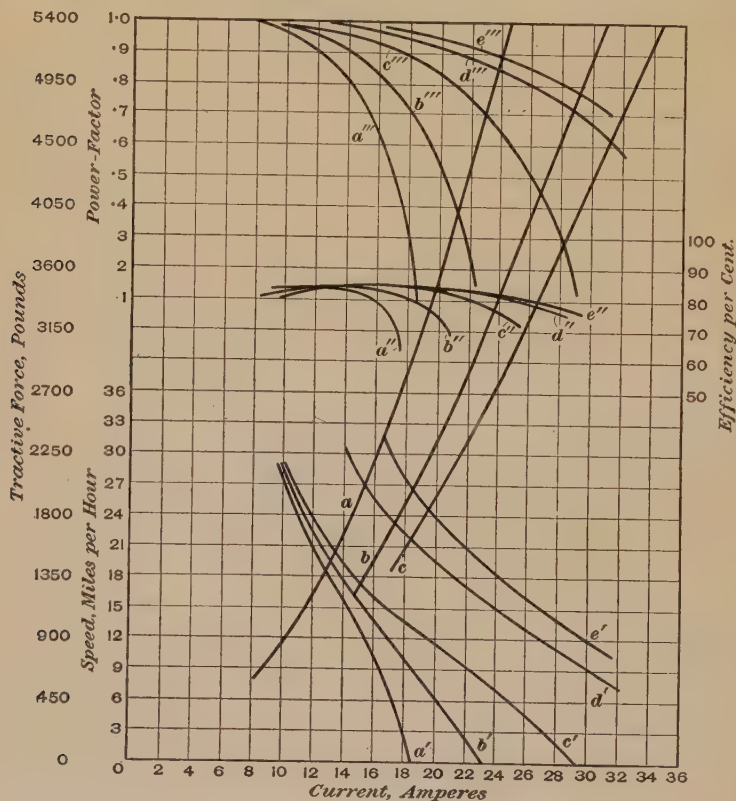


FIG. 20

the ratio at the right moment when starting, and using the correct ratio when running, the power factor can be kept very near unity.

56. **Curves for 200-Horsepower Motor.**—The curves for a railway motor with a rated capacity of 200 horsepower are given in

Fig. 20. The current is supplied at a pressure of 750 volts and a frequency of 25 cycles per second from the secondary of a step-down transformer, the primary of which is connected to the 6,000-volt overhead line. The relations between tractive effort and primary current for three positions of the controller are shown by the curves *a*, *b*, and *c*, the pull being measured at the tread of a driving wheel 39·375 inches in diameter. The speeds of the locomotive containing the motor are plotted against the primary current for five positions of the controller in curves *a'*, *b'*, *c'*, *d'*, and *e'*. The efficiencies are given by the curves *a''*, *b''*, *c''*, *d''*, and *e''*, and it should be noted that the efficiencies reach a maximum of 85 per cent., although all the losses in the main step-down transformer, the exciting transformer, the motor, and the gearing are taken into account. The power factors for the five controller positions are given by the curves *a'''*, *b'''*, *c'''*, *d'''*, and *e'''*.

CONSTRUCTION OF REPULSION MOTOR

57. Stator.—The construction of the stator of a six-pole compensated repulsion motor is shown in Fig. 21. The stator core *a* is built up of laminations, and is contained in a cast-iron stator housing *b*. The main field winding *c* consists of three coils per pole, and the commutation winding *d* is made of single coil, surrounding small sections at the centres of alternate poles. The effect of the commutating poles placed as shown is the same as though the windings were placed on every pole and each consisted of half as many turns.

58. Armature.—The armature corresponding to the stator just described is shown in Fig. 22. The winding is of the ordinary type used for direct current and consists of copper bars bent to shape and held in place in the partly closed slots by the insertion of wooden wedges. For purposes of ventilation, one end of the armature is provided with a centrifugal fan *a*, which communicates through ventilating ducts in the armature core and commutator spider with the apertures *b*. When the armature is revolving, air is expelled from the fan *a* and drawn

in at *b*, thus maintaining an air circulation which effectually cools the motor. The end connections to the commutator *c* are

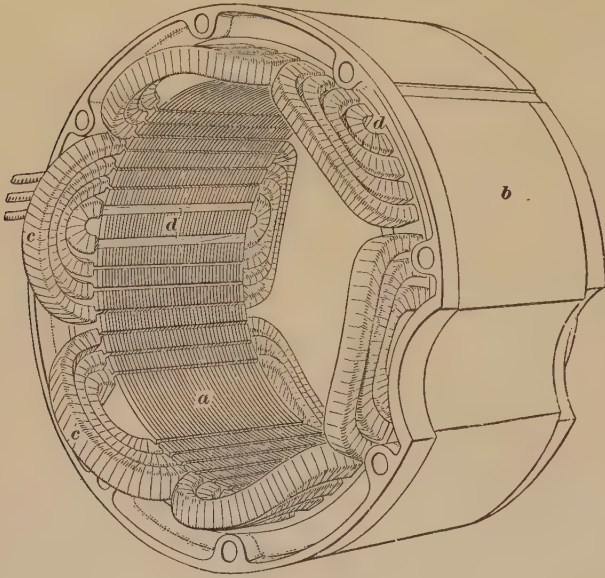


FIG. 21

covered in by a cap *d*, in order to prevent the accumulation of dust.

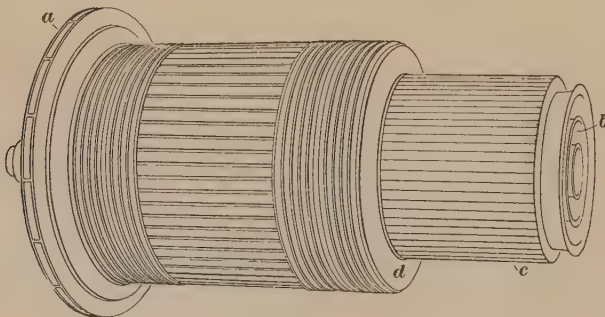


FIG. 22

59. The complete motor is illustrated in Fig. 23. The centrifugal fan *a* runs in an opening between the gear-case *b* and the

main housing *c* of the motor. The cast-iron housing is provided with a lug *d*, through which pass the bolts for attaching the motor to the truck of the locomotive or motor coach. The brush gear is totally enclosed in the case *e*, which is provided

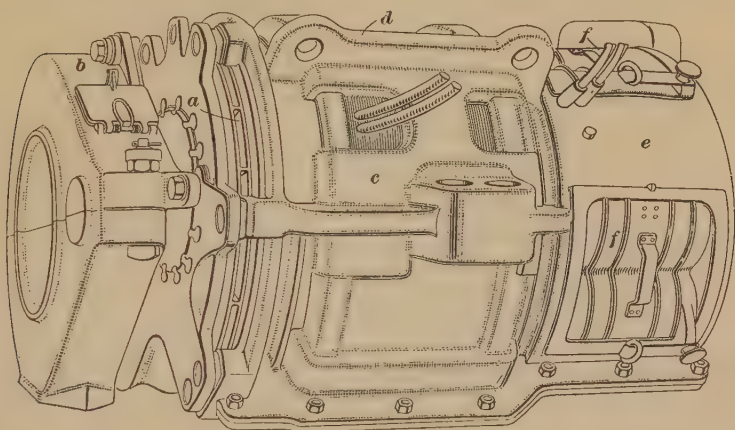


FIG. 23

with doors *f* for inspection purposes. The whole motor is very substantially constructed in order to withstand the severe vibration and shocks inseparable from railway work.

SYSTEMS OF MOTOR CONTROL

GENERAL PRINCIPLES

60. Control by Variation of Voltage.—Speed control of the single-phase railway motor is obtained by varying the voltage at its terminals, the same as with direct-current motors. Where alternating current is used, however, this can be done much more easily and economically than with direct current. Instead of first connecting the motors in series and then in parallel and using a variable resistance in the circuit with each grouping, as is done with direct-current motors, it is merely necessary to connect the alternating-current motors to different tappings on

the transformer or autotransformer. This is accomplished in small equipments, where single-car operation only is desired, by means of drum-type controllers that are similar in general appearance to those used with direct-current motors. In large equipments, or where multiple-unit train operation is desired, essentially the same connections are made by means of unit switches operated by compressed air from the air-brake system and controlled by electromagnetic valves, or by means of contactors operated by low-tension single-phase current and controlled directly from the master controller. The action of the magnet valves in the compressed-air system is regulated by a master controller, and current for operating them is generally supplied by a small 14-volt storage battery on the car.

61. Two- and Four-Motor Equipments.—When a car equipment consists of only two series motors, they are connected in parallel, so that in case of damage to either motor it may be cut out of circuit without interfering with the operation of the other. Where the equipment consists of four series motors, however, they are connected two in series, and these two groups are connected in parallel. In case of damage to one motor of a four-motor equipment, the pair of motors to which it belongs is cut out. This arrangement is used to reduce the cost of controllers, switches, wiring, etc., which, within the limits ordinarily used, depends on the current to be handled rather than on the voltage. Thus, the same controller or switch group is used with a given size of motor, whether the equipment consists of two or four motors.

62. Preventive Reactance Coil.—In the method of voltage variation by means of tappings on a transformer or autotransformer, it is necessary to be able to change from one voltage to another without breaking the main circuit. If this is done by means of a sliding contact, which makes contact with a new tapping at a higher or lower voltage before it leaves the old one, the section of the winding between the two tappings is short-circuited by the contact. In order to avoid this, choking coils, known as **preventive reactance coils**, are employed; these are connected as shown in Fig. 24. In view (a) the ends of

the preventive reactance coil *a* are shown connected to the tappings *c*, *d* of the autotransformer *b*, the middle point of the reactance coil being connected to the motor circuit. This connection is obtained when the controller is on the first notch

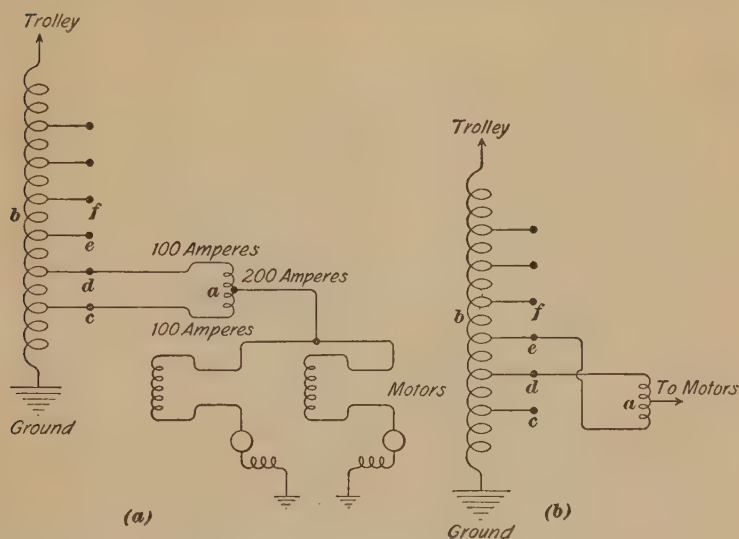


FIG. 24

and gives a low voltage to the motors. If the motors require 200 amperes, then 100 amperes flows through each of the tappings.

63. In order to increase the voltage applied to the motors the controller is moved to the second notch, and the lower end of the preventive coil *a*, Fig. 24 (b), is then disconnected from tapping *c* and connected to tapping *e* of the autotransformer *b*. The supply to the motors is not interrupted during the change, because the connection to tapping *d* is not broken. In order to raise the voltage another step, the connection to tapping *d* will be transferred to tapping *f*, leaving the connection to tapping *e* untouched. In addition to preventing the short-circuiting of transformer sections, the use of the preventive coil splits up the current taken by the motors into two parts, so that the contactors

used for making connection to the tappings need only be capable

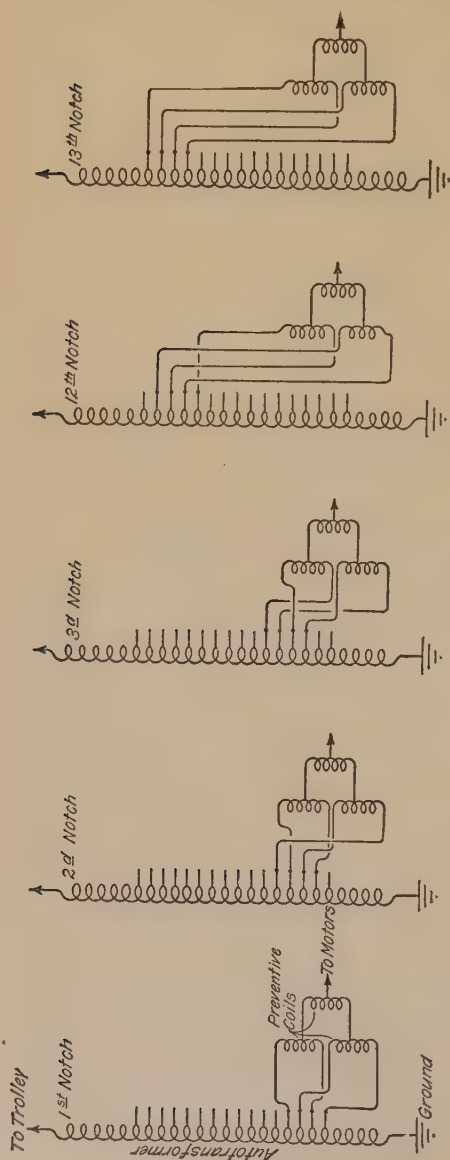


FIG. 25

of dealing with half the motor current. In cases where very heavy currents are to be handled, and a gradual voltage variation is required, three preventive coils may be used, as shown in Fig. 25, in which the method of gradually increasing the voltage by changing the connections one at a time is shown. In this case the total current is divided among four contacts.

64. Preventive Resistance.—For use in connection with drum-type controllers, a non-inductive resistance, called a **preventive resistance**, is connected in parallel with the preventive reactance coil, to reduce the sparking that may occur when breaking a tapping contact. Each half of the preventive reactance coil is bridged by one-half of the resistance. When one of the tapping

contacts is broken, the current suddenly decreases in one-half

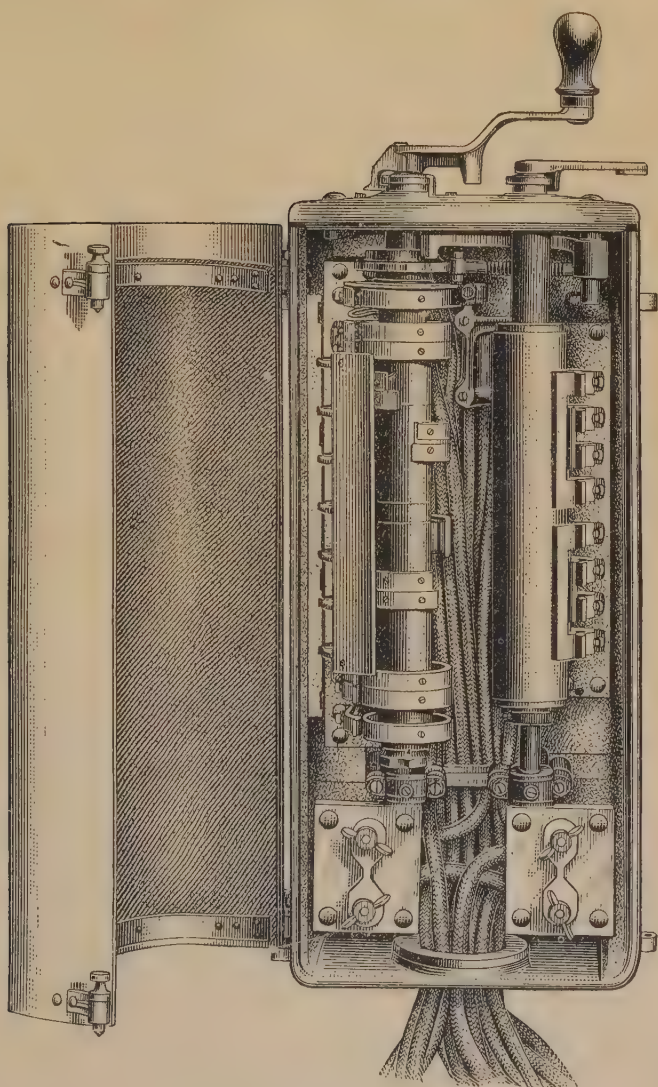


FIG. 26

of the reactance coil. This sets up a high E.M.F. due to the

inductance, and might cause sparking at the contact if it were not for the portion of the resistance through which the reactance coil may discharge and thus allow the current and the magnetic field to decrease in strength slowly. The preventive resistance is so proportioned that there is very little loss in it, and, in order to simplify the controller connections, it is left in circuit for all positions of the controller, except the last, where it can be cut out without adding complication. On account of the greater current-breaking capacity of unit switches, this resistance is not required where they are used.

65. Operation on Direct Current.—On some railways in America and on the Continent it is necessary to operate the equipment on direct current as well as on alternating current, in which case series motors must be used. The direct-current operation is generally through cities or towns, where the speed is necessarily limited, while the alternating-current operation is in the open country, where a high speed is usually desirable. The single-phase series motor will operate somewhat faster on direct current than it will on alternating current of the same voltage. If, therefore, two 250-volt alternating-current motors geared for the proper alternating-current speed are operated in series from a 500-volt direct-current trolley system, the speed will usually be very much higher than is required. On this account, equipments for operation on both alternating and direct current are usually provided with four motors. These motors are operated two in series in the ordinary way on alternating current, but are connected all four in series on direct current. With this arrangement, the speed of a car with normal direct-current voltage on the trolley is about two-thirds of that with normal alternating-current voltage. When operating on direct current, the motors are controlled in the ordinary way by means of a resistance in series with them.

DIRECT CONTROL FOR SERIES MOTORS

66. Controller.—A Westinghouse controller suitable for directly controlling two or four 50-horsepower series alternating-current motors is shown in Fig. 26. In general appearance this

controller is similar to a controller for direct-current operation. It contains a main power drum for connecting the various autotransformer tapings to the motor circuit, and a reverse drum for reversing the direction of rotation of the motor armatures.

Fig. 27 shows the preventive reactance coil,

and Fig. 28 the preventive resistance, used in connection with this controller.

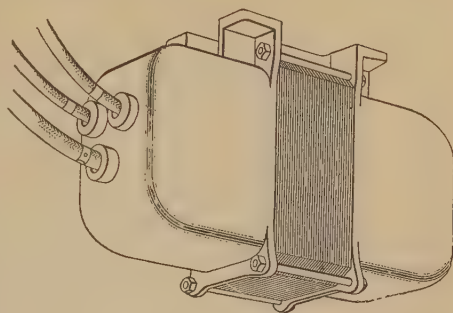


FIG. 27

67. Controller-Wiring Diagram. — An autotransformer with six secondary tapings and the wiring diagram of a hand controller arranged for connecting the several autotransformer tapings to the motor circuit is shown in Fig. 29. The tapings

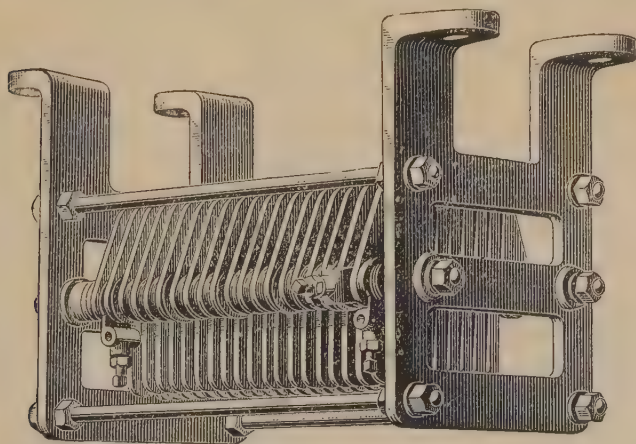


FIG. 28

provide E.M.F.'s of 160, 190, 220, 250, 280, and 310 volts. The E.M.F.'s impressed on the motor terminals differ slightly from these values, owing to the action of the preventive reactance coil. The motor circuits receive current from the middle

points of the preventive reactance coil and the preventive resistance, across which an E.M.F. of 30 volts is impressed.

68. When the controller, Fig. 29, is on the *first notch*, the contact fingers are in the position indicated by the dotted line *1* and fingers R_1 and C_1 are connected with finger L_2 (the 190-volt tapping), and fingers C_2 and R_2 are connected with finger L_1 (the 160-volt tapping). As R_1 and R_2 are the terminals of the preventive resistance, and C_1 and C_2 are the terminals of the preventive reactance coil, the E.M.F. impressed on the coils is 190 volts — 160 volts = 30 volts, and the E.M.F. at the middle

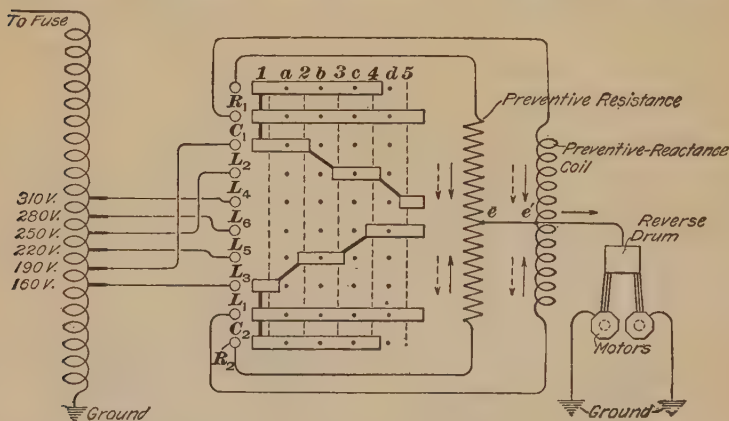


FIG. 29

points e, e' of the coils is 15 volts higher than the lower value and 15 volts lower than the higher value, or 175 volts. The E.M.F. of 30 volts forces currents through the resistance and the reactance coil independently of the operation of the motors. The directions of these currents are from the tapping that is, at a given instant, of a higher potential to the tapping that, at the same instant, is of a lower potential. The current therefore alternates through the coils.

69. *First Notch.*—If the trolley wire is positive at a certain instant and the controller is on notch *1*, Fig. 29, L_2 is at a higher potential than L_1 , and the E.M.F. of 30 volts tends to send currents through the preventive coils in the directions indicated by the dotted arrows. If the motor circuit is also active, the

currents from L_2 and L_1 flow to e and e' through the coils in the direction indicated by the full-line arrows. The motor currents in each half of a coil are in opposite directions and of nearly equal value. The currents join and flow to the motor circuit at the middle point of the coils. Where the normal exciting current of a coil and the motor current oppose each other, the motor current predominates and determines the direction of flow. At the particular instant under discussion, motor currents flow from the 190-volt tapping L_2 to e and e' , and from the 160-volt tapping L_1 to e and e' , there being an E.M.F. of approximately 175 volts impressed on the motor circuit.

70. Second Notch.—When the controller is passing from the first to the second notch, finger L_1 , Fig. 29, drops contact with its drum segment, while finger L_2 still remains in contact with its drum segment. Current then flows through the upper portions only of the preventive coils and to the motor circuit from the 190-volt tapping. The intermediate positions of the fingers are indicated by the dots under the letters a , b , c , and d . On the second notch, R_2 and C_2 are connected with finger L_3 (the 220-volt tapping), and R_1 and C_1 are still connected with L_2 (the 190-volt tapping). The impressed E.M.F. on the motor circuit is now 205 volts. At the intermediate position b , finger L_3 remains in contact with its drum segment, but finger L_2 drops contact with its segment. Therefore, current flows from the 220-volt tapping only.

71. Third Notch.—On notch 3, fingers L_4 and L_3 are active, and the E.M.F. impressed on the motor circuit is 235 volts. At the intermediate position c , finger L_4 remains in contact with its drum segment, but finger L_3 drops contact with its segment. Current now flows from the 250-volt tapping only.

72. Fourth Notch.—On notch 4, fingers L_5 and L_4 are in service, and the E.M.F. impressed on the motor circuit is 265 volts. As fingers R_1 and R_2 drop contact with their drum segments at intermediate position d , the preventive resistance is cut out of circuit. Finger L_5 and the lower half of the reactance coil are alone active at this point, and current now flows from the 280-volt tapping to the motors.

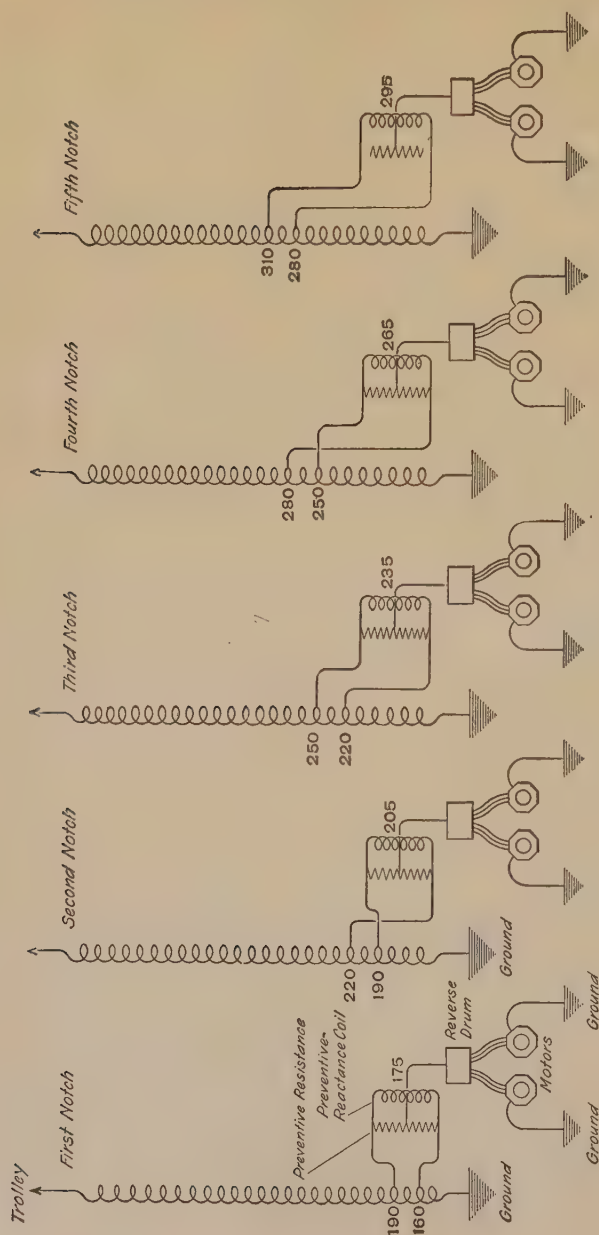
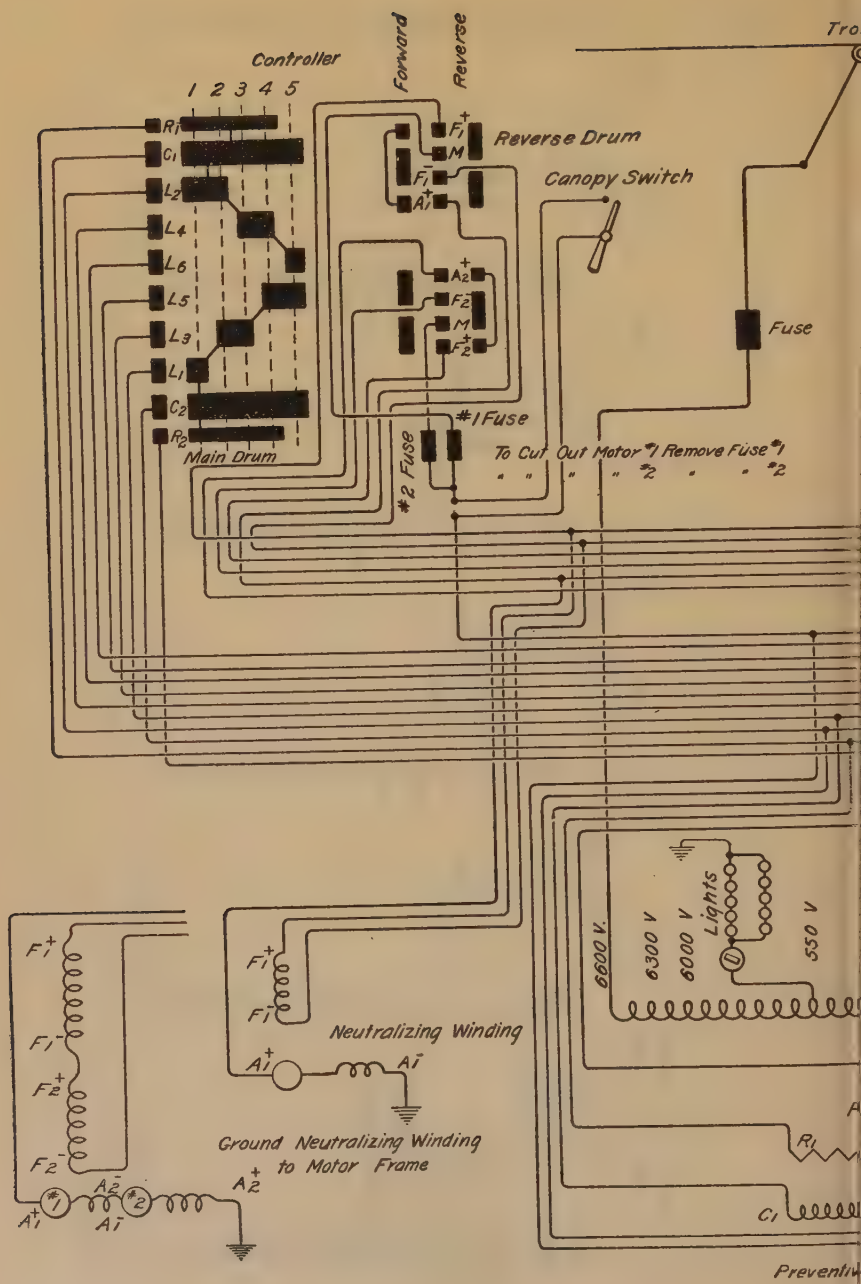
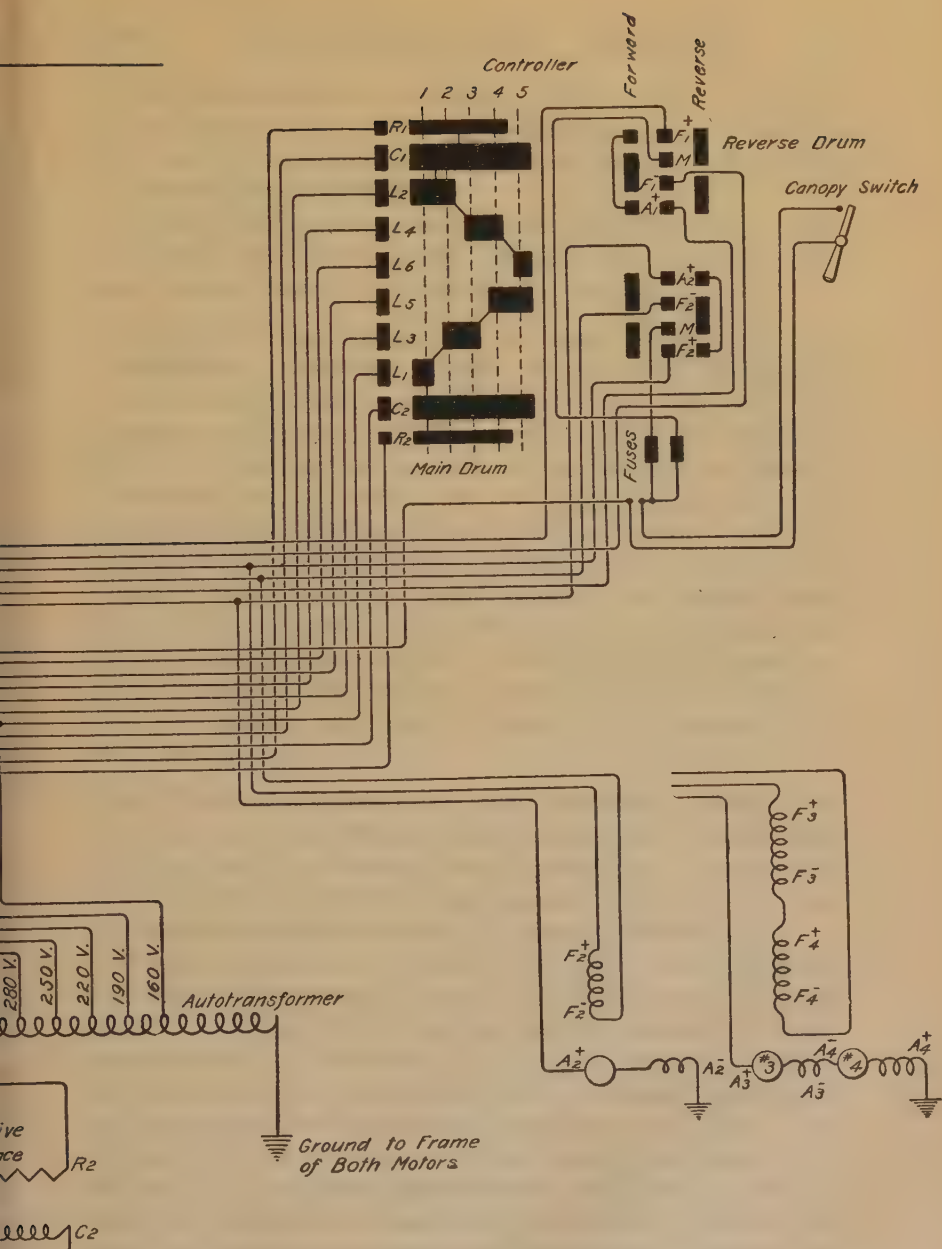
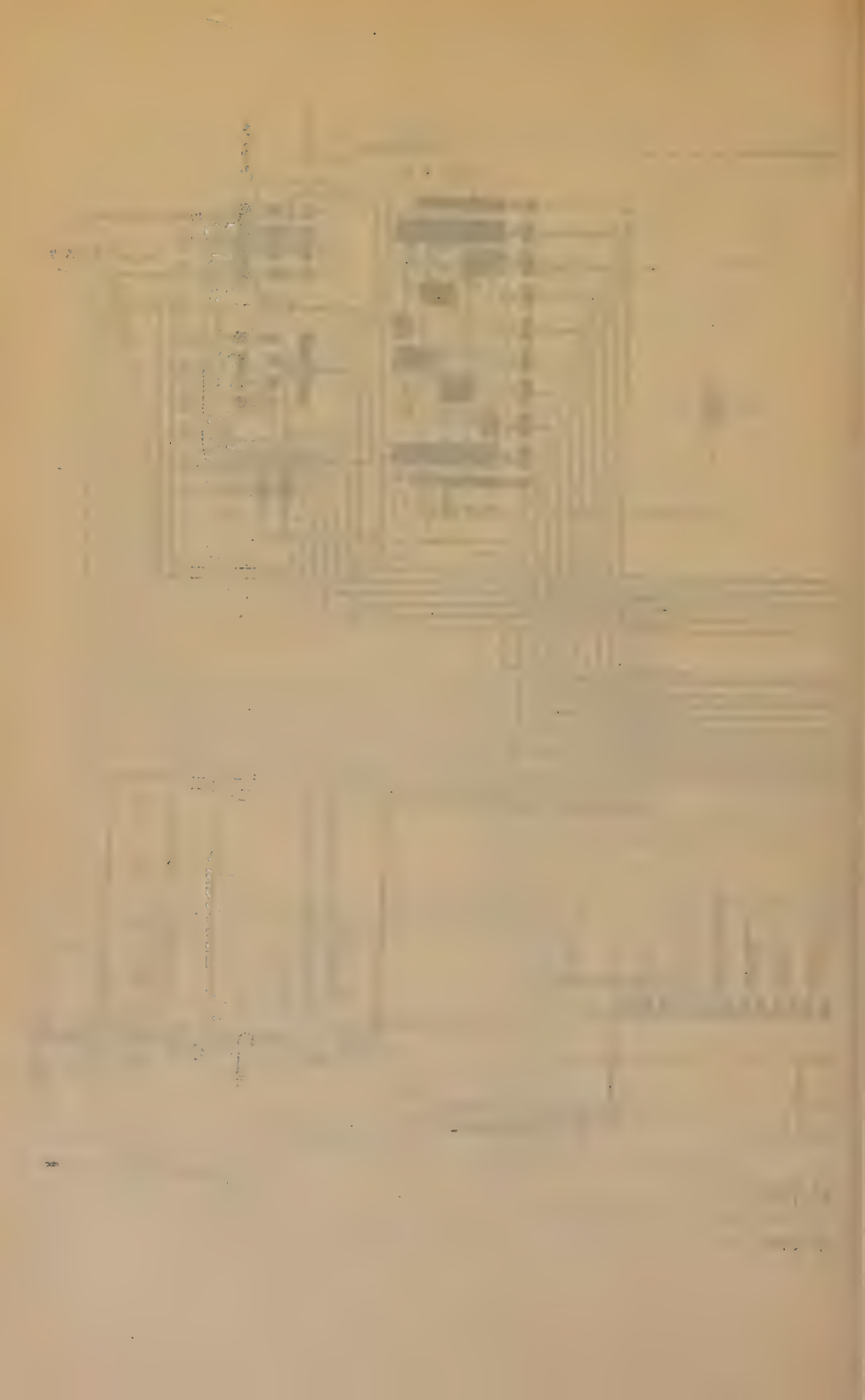


FIG 30







73. Fifth Notch.—At the final notch 5, fingers L_6 and L_5 are active, and both sections of the reactance coil carry currents to e' and to the motor circuit. The final E.M.F. impressed on the motor circuit is 295 volts.

In Fig. 30 is shown the voltages of the tapings and the motor circuits for the five controller notches. Any of these notches may be used efficiently for running, if so desired.

74. Car-Wiring Diagram.—A car-wiring diagram for two Westinghouse controllers suitable for the direct operation of two or four 50-horsepower motors is shown in Fig. 31. The operation of the main controller drum has just been explained. The wire from the middle M of the preventive coils leads to a car wire that is connected to two fingers marked M on the reverse drum of each controller. The two motors are permanently connected in parallel. The upper half of each reverse drum controls motor No. 1, and the lower half controls motor No. 2. The essential parts of the apparatus are indicated on the diagram by name or letter; the lettering of the main controller corresponds to the lettering used in Fig. 29. In place of the word *number*, the sign # is used on the diagram; thus, *motor # 1* means *motor No. 1*.

75. When the reverse drum of the controller is thrown from one position to the other, the field terminals are interchanged, while the armature terminals remain unchanged; this reverses the direction of rotation of the motors. The armatures and the series neutralizing windings are permanently earthed.

If four motors are to be used, motors Nos. 1 and 2, Fig. 31, are connected permanently in series, as indicated by the small sketch on the left of the diagram, and are considered as one unit, so far as the controller connections are concerned. Motors Nos. 3 and 4 are also connected in series, as shown by the sketch on the right of the diagram, and considered as one unit. The two pairs of motors thus formed are connected in parallel. In the case of large railway equipments for heavy service, the currents are too large to be handled directly on the ordinary drum controller, and have to be dealt with by contactors operated by compressed air or by solenoids controlled from a master controller.

WESTINGHOUSE ALTERNATING-CURRENT UNIT-SWITCH CONTROL

76. Master Controller.—The controlling apparatus used with the Westinghouse unit-switch alternating-current control system is, in general, similar to that employed in the Westinghouse unit-switch control systems arranged for direct-current motors.

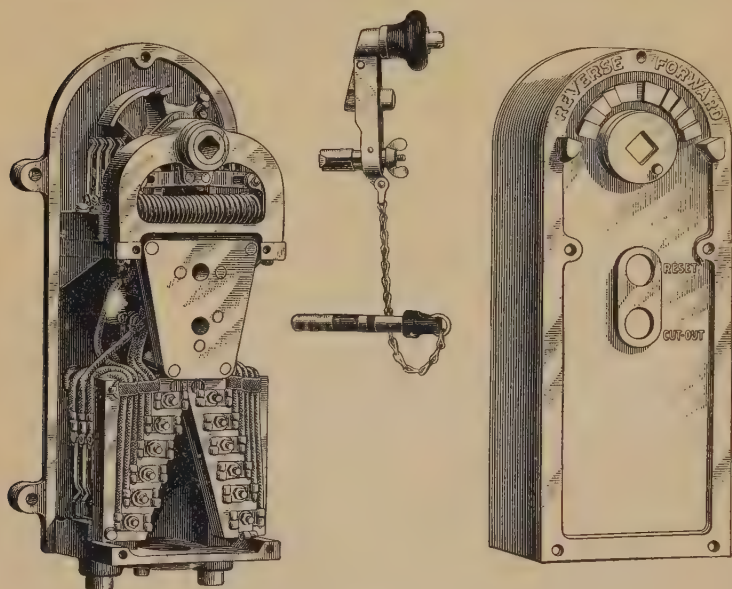


FIG. 32

A small storage battery furnishes the direct current for the control circuits in both systems. A view of a master controller for an alternating-current equipment of two or four motors is shown in Fig. 32. The controller is small, as it carries only sufficient current to actuate the control apparatus.

77. Diagram of Connections.—A car-wiring diagram for a unit-switch group and two 100-horsepower motors is shown in Fig. 33. For a four-motor equipment of the same size of motors, operating on a 3,300-volt circuit, the connections are essentially the same. In the latter case, however, the motors are connected two in series. With a four-motor equipment of such

motors, on a 6,600-volt circuit, a circuit-breaker is used in the high-tension circuit instead of a fuse.

78. Operation of Current Collector.—The *pantograph* type of current collector is indicated in Fig. 33. The collecting bow is raised into contact with the trolley wire by springs and is lowered by air pressure, both movements being controlled by magnets and air valves. The storage-battery switch is closed, so that one of the two batteries is connected to the control circuit. To raise the collecting bow the plug shown in Fig. 32 is inserted in the reset receptacle on controller No. 1, Fig. 33, thus joining contacts $B+$ and 6. Starting from the positive battery terminal $B+$, the current path is as follows: $B+$ —knife switch— $B+$ —terminal $B+$ in junction box 2— $B+$ in junction box 1— $B+$ in reset receptacle of controller No. 1—wire 6—terminal 6 in junction box 1—6 in junction box 2—wire 6—right-hand valve magnet under the pantograph trolley-wire 91 to interlock $A1$ of switch 11 in switch group—wire 93 to interlock $A1$ of switch 9—negative battery wire $B-$ to negative terminal of the battery. The right-hand trolley valve magnet is energized, admitting air to the trolley unlock cylinder; this releases the latch that holds the collecting bow in its lower position and allows powerful springs to raise the bow into its active position.

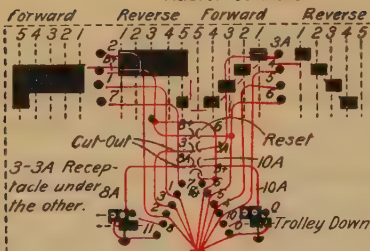
79. To lower the collecting bow, the controller plug, which has two metal portions insulated from each other, is inserted in the cut-out receptacle, thus connecting together the front cut-out receptacle contacts $B+$, 8A, and 10A on controller No. 1, Fig. 33, and also the back cut-out receptacle contacts 3 and 3A. The right-hand button, indicated near the base of the controller, is then pressed. The button temporarily raises the contact segments so that fingers 10A and 0 are connected. Starting from the front cut-out receptacle contact $B+$ on the controller, the path is: $B+$ —plug—contact 10A—finger 10A—contact segment—finger 0—wire 0, through junction boxes 1 and 2 to the left-hand valve magnet under the pantograph trolley-wire $B-$ to negative terminal of the battery. The valve magnet admits air to the control cylinders and forces the collecting bow to its lower position, where it is locked. All of the current collectors on the

train may be operated from any one of the master controllers through the interconnecting control wires on the cars.

80. Control Circuits, First Notch.—After the current collector has been raised into contact with the trolley wire by the insertion of the plug into the reset receptacle of the master controller, the plug is inserted into the cut-out receptacle. Since the button on the controller base is not pressed, the circuit of the valve magnet for lowering the collecting bow is open. One of the metal portions of the plug connects receptacle contacts *3* and *3A*, Fig. 33. In order to obtain forward movement of the car, the controller handle is moved toward the right. On the first forward notch, drum finger *B+* is connected through one of the drum segments, all of which are electrically connected, to finger *1*. The path is: finger *B+*—finger *1*—wire *1*—terminals *1* in junction boxes *1* and *2*—wire *1* to reverser interlock—wire *R1*—reverser operating coil *R1*—wire *90* to interlock *AA1* of switch *12* of switch group—wire *92*—interlock *AA1* of switch *10*—wire *B*—to negative terminal of battery. The reverser is thrown to forward position, and reverser interlock fingers *1* and *R* are connected by the lower reverser interlock segment. Current from the battery finger *B+* on the master controller now flows through wire *1* to the lower reverser interlock segment—wire *R* to switch group—wires *11* and *12* in parallel—switch operating coils *9*, *10*, *11*, and *12* in parallel. This operates main switches *9*, *10*, *11*, and *12* and moves their interlocks so that the fingers occupy the position marked *switch closed*. At the same time finger *B+* on the master controller is connected to finger *3A* and current flows through finger *3A*—plug contact—wire *3*—terminals *3* in junction boxes *1* and *2*—wire *3* to switch group—interlock *K* of switch *5*—wire *3*—switch—operating coil *1*—wire *B*—to negative terminal of battery. Main switch *1* is closed and its interlock *V* is in the *switch-closed* position. The closing of main switch *1* connects tapping *1* of the autotransformer to end *1* of the right-hand preventive coil.

81. Since the interlocks under switches *1*, *9*, and *11* of the switch group, Fig. 33, are closed, current can flow from wire *R* under the interlock of switch *11* to interlock *A1*—wire *13*—

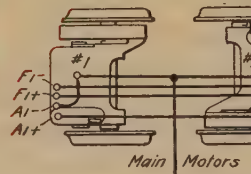
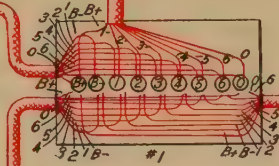
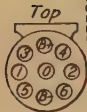
Master Controller



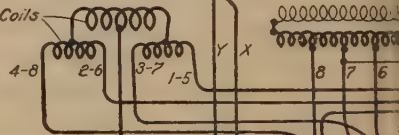
No. 1

Pantograph Trolley

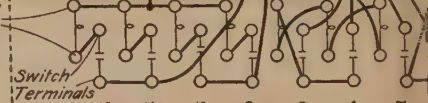
To lower Trolley, insert Plug in Cut-Out Receptacle and press Button.
To raise Trolley, insert Plug in Reset Receptacle
Plug must be in Cut-Out Receptacle to obtain proper operation of Master Controller



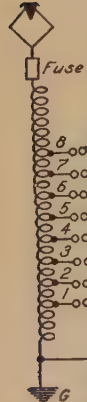
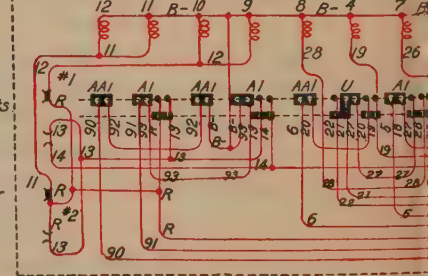
Preventive Coils



Blow-Out Coil Terminals



Motor Cut-Outs

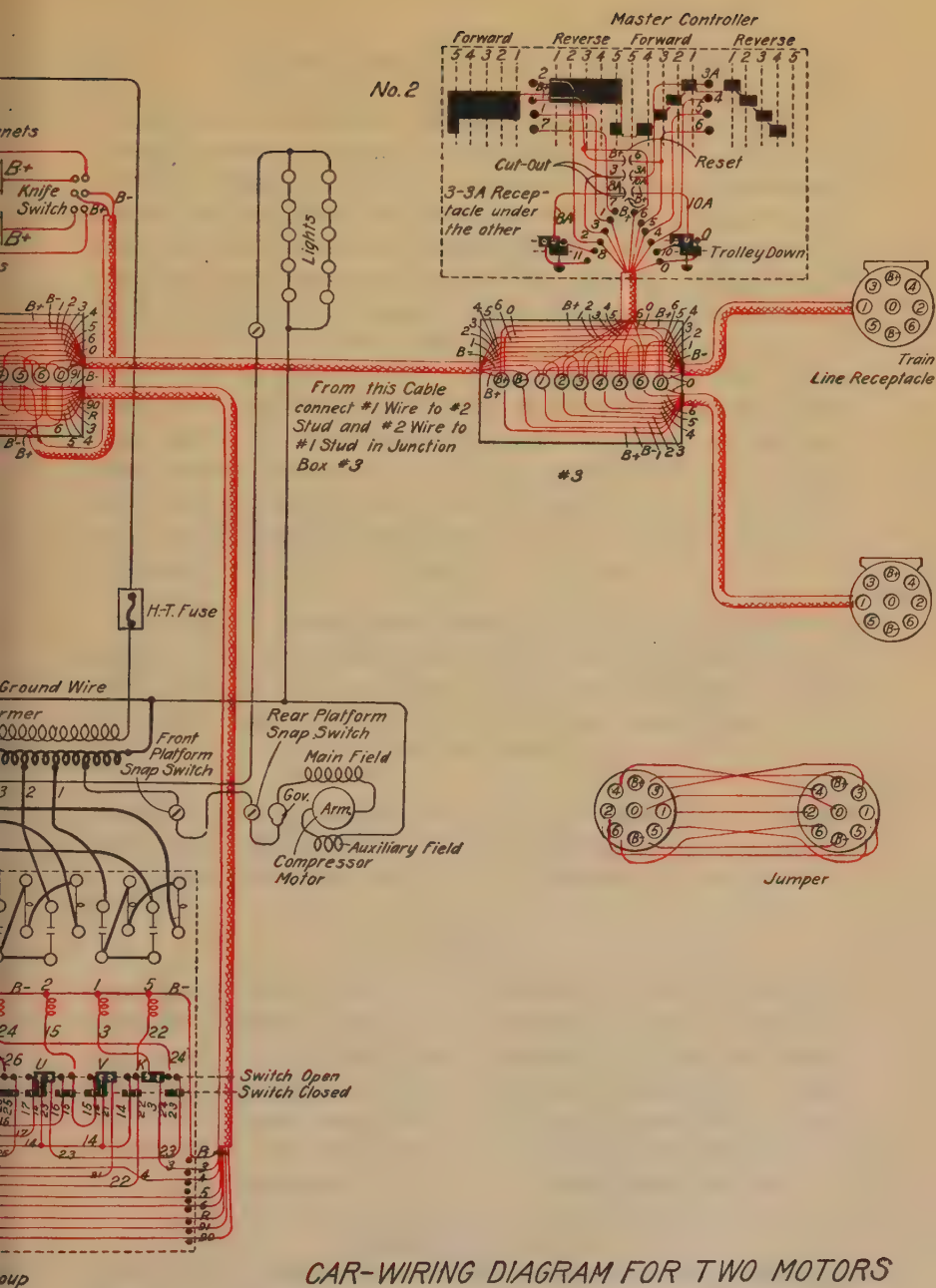


Schematic Diagram

Switch	1	2	3	4	5	6	7	8	9	10	11	12
1	1	2							9	10	11	12
	1	2	3						9	10	11	12
	1	2	3	4					9	10	11	12
2	2	3	4	5					9	10	11	12
3		3	4	5	6				9	10	11	12
4			4	5	6	7			9	10	11	12
5				5	6	7	8	9	10	11	12	

Sequence of Switches

To cut out a Motor, remove Plug from upper Receptacle and insert in lower Receptacle.

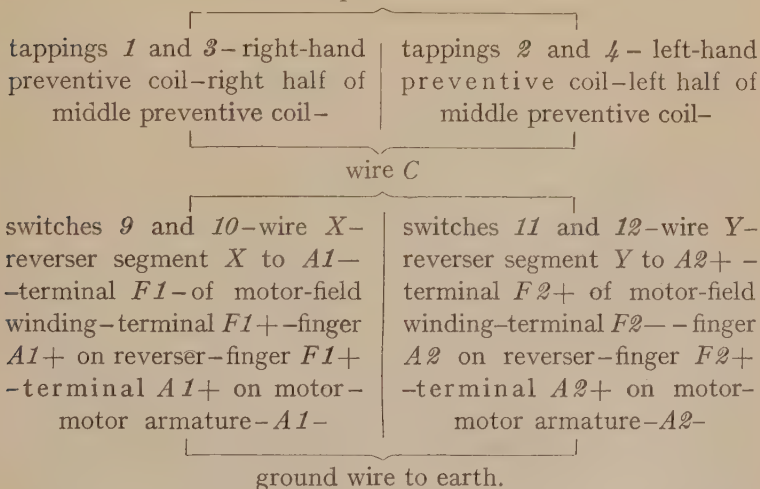


CAR-WIRING DIAGRAM FOR TWO MOTORS

interlock *A1* of switch *9*-wire *14* to interlock *V* of switch *1*-wire *15*-switch-operating coil *2*-wire *B*- to negative terminal of battery. Main switch *2* is now closed, connecting autotransformer tapping *2* to end *2* of the left-hand preventive coil. Since the interlock under main switch *2* is now closed, current can flow from junction *14* under this interlock through interlock *U* of switch *2*-wire *17*-switch-operating coil *3*-wire *B*-. Main switch *3* is closed, connecting tapping *3* to end *3* of the right-hand preventive coil. Since interlock *U* under main switch *3* is now closed, current can flow from junction *14*, under this interlock, to wire *19*-switch-operating coil *4*-wire *B*-. Main switch *4* is closed, connecting tapping *4* to end *4* of the left-hand preventive coil. Main switches *1*, *2*, *3*, *4*, *9*, *10*, *11*, and *12* and their interlocks are closed on the first notch, as indicated in the table of sequence of switches.

82. Motor Circuit, First Notch.—The circuit through the motors when the master controller is on the first forward notch is as follows: Main switches *1*, *2*, *3*, and *4*, Fig. 33, are connected to tappings *1*, *2*, *3*, and *4* on the autotransformer.

The path is from



The only change in the motor circuit for the succeeding notches of the master controller is in the connections to different

tappings of the autotransformer. The schematic diagram shows the essential motor circuits in simplified form. The shunts across the field coils of the motors are not always used. The effect of the shunts is to reduce the voltage drop across the fields and change the phase relation between the current in the armature and field to a greater or less extent.

83. Second Notch.—On the second notch, finger *3A*, Fig. 33, drops contact, and finger *4* makes contact with the drum of the master controller. Opening the circuit of the finger *3A* opens main switch *1*, thus disconnecting tapping *1* on the autotransformer and moving interlock *V* to the *switch-open* position. From drum finger *4*, current flows through wire *4* to the switch group—interlock *A1* of switch *6*—wire *16*—interlock *U*—wire *15*—switch—operating coil *2*—wire *B*— to negative terminal of battery. Switch *2* is thus held closed, although its control path through interlock *V* is broken. From junction *14*, under interlock *V*, current can now flow through interlock *V* to wire *21*—interlock *U* (closed)—wire *22*—switch—operating coil *5*—*B*—. Main switch *5* and its interlock are closed, and tapping *5* is connected to end *5* of the right-hand preventive coil. Switches *2*, *3*, *4*, *5*, *9*, *10*, *11*, and *12* are closed on the second notch.

84. Third Notch.—On the third notch, finger *4*, Fig. 33, drops contact, and finger *5* makes contact with the drum of the master controller. The circuit through wire *4* is broken, thus allowing main switch *2* and its interlock *U* to open. Current from drum finger *5* now flows through interlock *A1* of switch *7*—wire *18*—interlock *U* of switch *3* (closed)—wire *17*—operating coil *3*—wire *B*—. Switch *3* is thus held closed, although its control path through interlock *U* of switch *2* is open. Current from junction *14*, under interlock *U* of switch *2* can flow through interlock *U*—wire *23*—interlock *K* (closed)—wire *24*—operating coil *6*—wire *B*—. Main switch *6* and its interlock are closed. Tapping *6* is connected to end *6* of the left-hand preventive coil. Switches *3*, *4*, *5*, *6*, *9*, *10*, *11*, and *12* are closed on the third notch.

85. Fourth Notch.—On the fourth notch, finger *5*, Fig. 33, drops contact and finger *6* makes contact with the drum of the

master controller. The circuit through wire 5 is broken, thus allowing main switch 3 and its interlock *U* to open. From drum finger 6, current now flows through interlock *AA1* of switch 8—wire 20—interlock *U* (closed)—wire 19—switch-operating coil 4—wire *B*—. Switch 4 is held closed, although its control path through interlock *U* of switch 3 is open. Current from junction 14 can now flow through interlock *U* of switch 3—wire 25—interlock *A1* of switch 6 (closed)—wire 26—switch-operating coil 7—*B*—. Main switch 7 and its interlock are closed. Tapping 7 is connected to end 7 of the right-hand preventive coil. Switches 4, 5, 6, 7, 9, 10, 11, and 12 are closed on the fourth notch.

86. Fifth Notch.—On the fifth notch, finger 6, Fig. 33, drops contact, and finger 7 makes contact with the controller drum. Control circuit through wire 6 is broken, thus allowing main switch 4 and its interlock to open. Current cannot flow from drum finger 7, since controller terminal 7 is not connected to any car wire. Interlock *U* of switch 4 is open, so that current can flow from junction 14 under interlock *V* of switch 1—wire 21—interlock *U*—wire 27—interlock *A1* of switch 7 (closed)—wire 28—switch-operating coil 8—*B*—. Main switch 8 and its interlock are closed. Tapping 8 is connected to end 8 of the left-hand preventive coil. Switches 5, 6, 7, 8, 9, 10, 11, and 12 are closed on the fifth notch.

87. First Reverse Notch.—To reverse the direction of movement of the car the controller handle is moved to left. On the first reverse notch, Fig. 33, drum fingers *B+* and 2 are active. Current flows from drum finger 2—wire 2—junction boxes 1 and 2—wire 2—reverser interlock segment—wire *R2*, now connected to 2, as the reverser control segments are assumed to be at forward position—operating coil *R2*—wire 90 to switch group—wire 90—90—interlock *AA1* of switch 12—wire 92—interlock *AA1* of switch 10—wire *B*—. The reverser operating coil *R2* forces the reverser contact segments to reverse position. Reverser interlock finger *R2* drops contact with the interlock segment, thus breaking connection between it and finger 2. At the same time, finger *R* makes contact with the same segment. Current flows

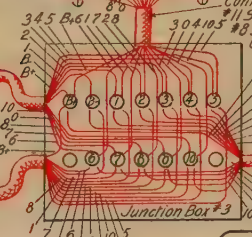
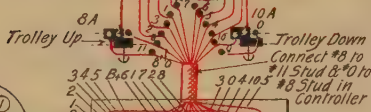
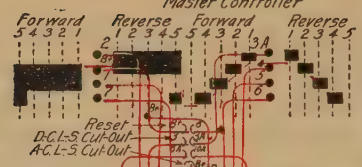
from reverser finger 2 to finger *R*—wire *R* to switch group—wire *R*—switch-operating coils 9, 10, 11, and 12, in parallel, thus operating the main switches 9, 10, 11, and 12. The action of the other control magnets and main switches is the same on the reverse notches as on the forward notches. The main field-coil connections of the motors are reversed, therefore the rotation of the motors is reversed.

WESTINGHOUSE ALTERNATING-CURRENT AND DIRECT-CURRENT UNIT SWITCH CONTROL

88. Apparatus for Direct and Alternating Current.—A diagram of the wiring of a car fitted with four motors and adapted to operate with either direct or alternating current is shown in Fig. 34. For direct-current working the motors are controlled by resistances, and for alternating current by an autotransformer. The requisite changes in connections are made by a change-over switch operated by a relay. Two types of current collectors are used: one of the pantograph type for use on high-tension alternating-current circuits, and the other of the ordinary wheel type similar to that used on tramcars for use on direct-current circuits.

89. Arrangement for Direct Current.—When the equipment is to be used on a direct-current circuit, one of the arms carrying a trolley wheel is raised so that contact is made with the trolley wire. Current then flows from the current collector through the coil of the direct-current relay and to earth at *G*, Fig. 34. The plunger of the relay is drawn up, thus making connection between the upper contacts 81. The change-over switch is placed in the proper position for direct-current operation as follows: The plug of the left-hand master controller is placed in the alternating-current line-switch cut-out receptacle so that contact *B*+ is connected to contact 8*A*, and current flows to contact 8*A*—stud 11—wire 8—contact points 80 on *A. C.* relay (lower position)—contacts 81 on *D. C.* relay, as relay is now active—wire 81 to operating coil of change-over switch—wire 83—change-over switch interlock segment, if switch has been left at *A. C.* position—wire *B*— to negative terminal of battery. The switch is pulled to the direct-current position shown in the diagram.

Master Controller

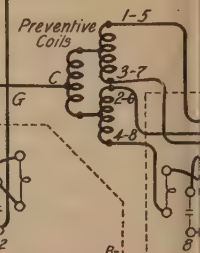
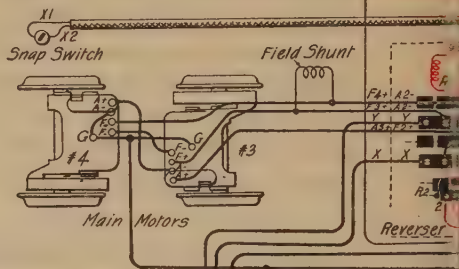
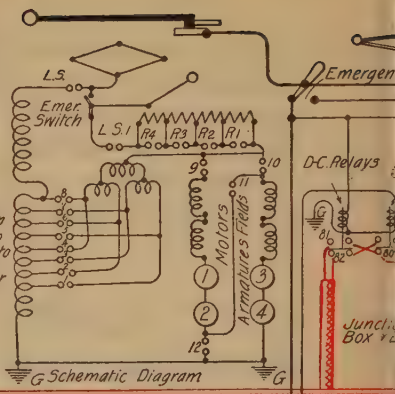
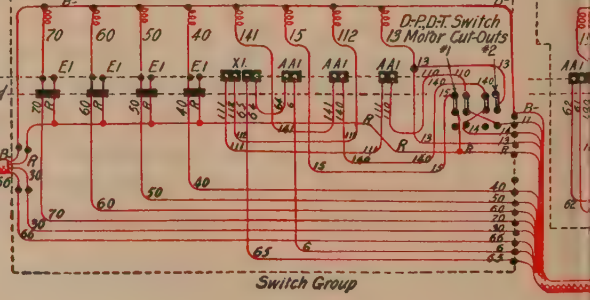
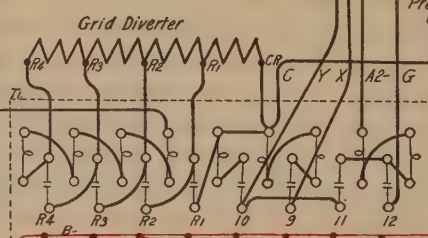
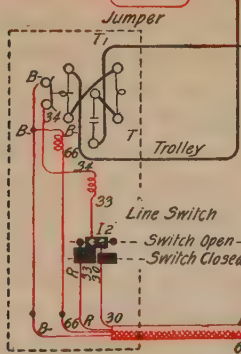
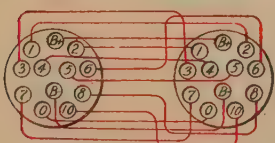


Receptacle Cable Colors

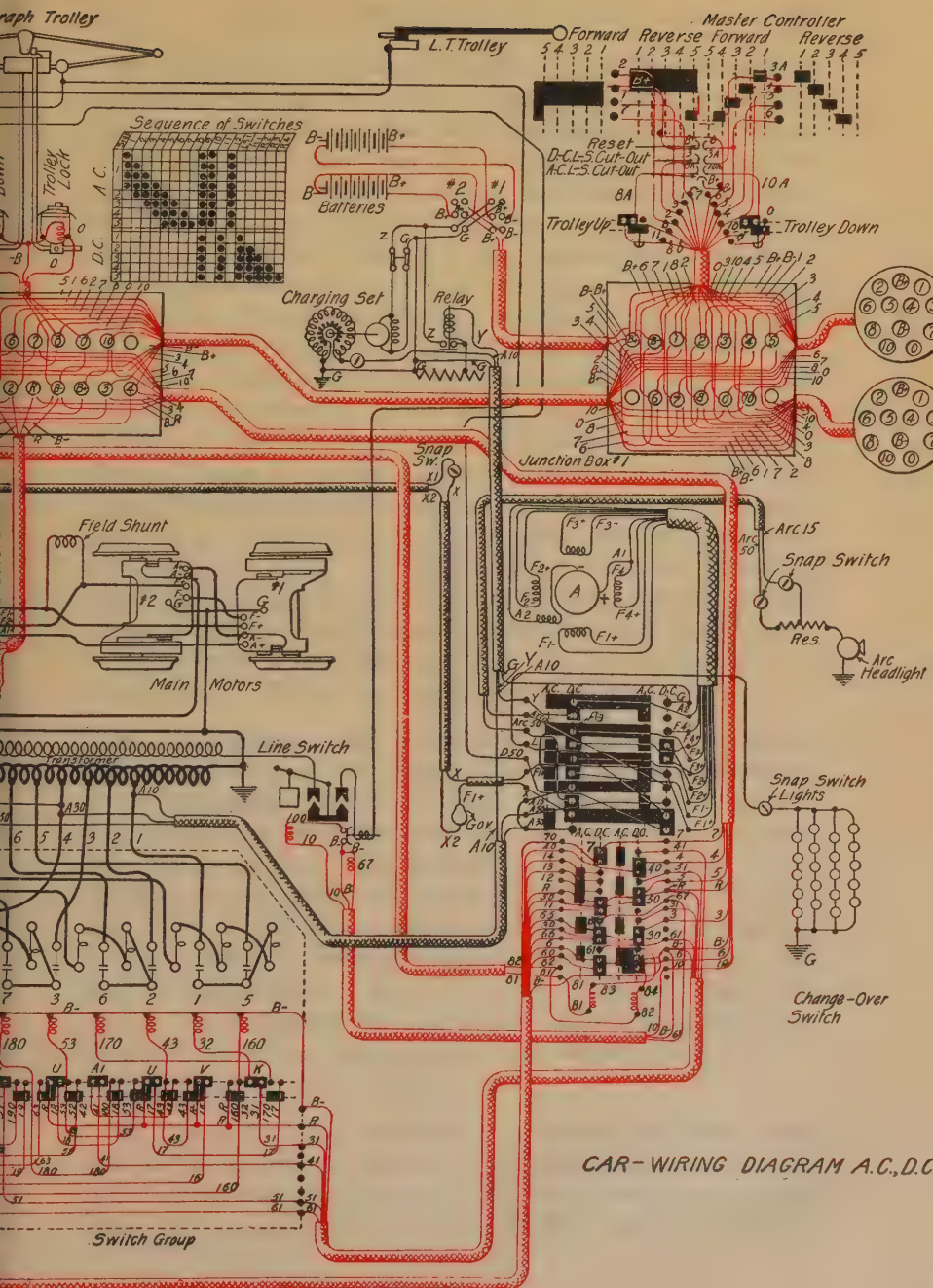
- | | |
|----|----------------|
| B+ | Red |
| 1 | Green & White |
| 3 | Yellow & White |
| 7 | Green |
| 0 | Red & Black |
| 10 | Yellow |
| 8 | White |
| 6 | Black & White |
| 2 | Red & Green |
| 5 | Green & Black |
| 4 | Red & White |
| B- | Black |

Jumper Cable Colors

- | | |
|----|----------------|
| B+ | Red |
| 2 | Red & Green |
| 6 | Black & White |
| 8 | White |
| 10 | Yellow |
| 0 | Red & Black |
| 7 | Green |
| 3 | Yellow & White |
| 1 | Green & White |
| 4 | Red & White |
| 5 | Green & Black |
| B- | Black |



graph Trolley



CAR-WIRING DIAGRAM A.C./D.C.

90. Operation on Direct Current.—After the change-over switch has been set for direct current, the plug of the master controller is placed in the direct-current line-switch cut-out receptacle. When the controller handle is moved to the first notch, finger *3A*, Fig. 34, is active, and current flows through the plug to contact *3*-wire *3* to finger *30* on the change-over switch-wire *30*-interlock of *D. C.* line switch-wire *33*-line-switch operating coil-wire *34*-wire *B*—. The line switch is thus closed. Finger *1* on the master controller is used for forward running, and when this finger is active, the reverser operating coil *R1* is energized and the reverser is thrown to forward position. Wire *R* at the reverser interlock is now active, and, as the operating coil of switch *9* takes current from this wire through wire *15*, switch *9* closes. Finger *11* on the change-over switch is energized from finger *R*, and current flows through wire *11* to the switch group-wire *110*-interlock *AA1* of switch *12*-wire *111*-wire *112*-operating coil of switch *11*. Switch *11* closes. The four motors are in series, with all the resistance sections in circuit. Further movement of the controller energizes fingers *4*, *5*, *6*, and *7* and cuts out the four resistance sections. The four motors are now in series, with all the resistance sections cut out.

91. Arrangement for Alternating Current.—If alternating current is to be used, the plug of the master controller is inserted in the alternating-current line-switch cut-out receptacle, Fig. 34. The alternating-current line switch is closed by current that flows from the plug contact *B+* through cut-out contact *10A* - finger *10* - wire *10* - operating coil of the *A. C.* line switch - wire *100* - wire *B*— to negative terminal of battery. The pantograph current collector is raised by pressing the left-hand button at the base of the controller. Stud *8* and wire *0* are now active, and current flows through the operating coil of the trolley lock. The latch on the pantograph collector is released, and the collecting bow is forced upwards by springs.

92. As soon as the collecting bow touches the trolley wire, current flows through the coil of the alternating-current relay from autotransformer tapping *4*, Fig. 34. The plunger of the relay is raised so that contact is broken between the lower

points 80. Therefore, when the left-hand button on the base of the controller is released and finger 8A is connected to stud 11 and wire 8, no current can flow between the lower relay contacts 80 and through the trolley-down magnet. The change-over switch is forced to its alternating-current position by current flowing from the positive battery terminal to the contact B+ of the controller plug-stud 11-wire 8-upper contact 8 on the alternating-current relay across the disc to contacts 82 of D. C. relay-wire 82-operating coil of change-over switch-wire 84-wire B—to negative terminal of battery. If the switch is in direct-current position, it is pulled into alternating-current position.

93. Operation on First Notch.—On the first notch of the master controller, either finger 1 or finger 2, Fig. 34, is active, depending on whether the controller is thrown to forward or to reverse position. In either case wire R at the reverser interlock is energized, and this energizes wires 14 and 13 at the interlocks of the change-over switch, which is in the alternating-current position. Switches 9, 10, and 12 are thus closed. Switch 1 is closed by current through master-controller finger B+ -finger 3A-wire 3-segment of change-over switch-wire 31-wire 32-operating coil of switch 1. Switch 2 is closed by current from wire R through the closed interlock of switch 1 and wire 43. Switch 3 is closed by the current passing through the closed interlock of switch 2 and wire 53. Switch 4 is closed by the current passing through the closed interlock of switch 3 and wire 63.

94. Operation on Second and Third Notches.—On the second notch, finger 3A, Fig. 34, drops contact and switch 1 opens. When wire 4 becomes active, wire 41 is energized at the change-over switch and switch 2 is held closed. The current can now flow through the wire R-interlock of switch 1 (open)-wire 16-interlock of switch 4 (closed)-wire 160-operating coil of switch 5. Switch 5 closes.

On the third notch, finger 4 drops contact, and finger 5 is energized. Switch 2 opens, since wire 41 is dead, and circuit R, through its operating coil, was broken when switch 1 opened. Current from wire R flows through the interlock of switch 2

(open)—wire 17—interlock of switch 5 (closed)—operating coil of switch 6. Switch 6 closes. Circuit *R*, through the operating coil of switch 3, is broken by the interlock of switch 2 (now open), but current flows through operating coil 3 from wire 51.

95. Operation on Fourth and Fifth Notches.—On the **fourth notch**, wires 5 and 51, Fig. 34, are dead, and wire 61 is active. Switch 3 opens because wire 51 is dead. Current from the wire *R* flows through the interlock of switch 3 (open)—wire 18—wire 180—operating coil of switch 7. Switch 7 closes. Circuit *R*, through the operating coil of switch 4, is now broken, but the coil obtains current from wire 61.

On the **fifth notch**, wires 6 and 61 are dead, and switch 4 opens. Wire 7 is dead when the change-over switch is at its alternating-current position. Current from circuit *R* can now flow through the interlock of switch 1—wire 16—wire 19—wire 190—operating coil of switch 8. Switch 8 closes. The maximum E.M.F. is now impressed on the motors.

96. Method of Lowering Pantograph Collector.—If the current collector is to be lowered, the right-hand button of the master controller is pressed, thus breaking the circuit of wire 10 and causing the alternating-current line switch to open. The alternating-current relay contact plate drops and completes wire circuit 8 through the trolley-down magnet. Air under pressure is forced into the main cylinder of the pantograph, and the collecting bow is lowered and automatically latched. If the collecting bow is to remain down, the plug may be drawn out of the alternating-current line-switch cut-out.

SPRAGUE GENERAL ELECTRIC ALTERNATING-CURRENT MULTIPLE-UNIT SYSTEM

97. In the Sprague General Electric alternating-current multiple-unit system the contactors are operated by alternating-current electromagnets, which are supplied with current at low tension from the autotransformer and controlled from a master controller, which is shown in Fig. 35 (*a*). The segments opposite the eight lower fingers *b* to *g*, view (*b*), constitute the

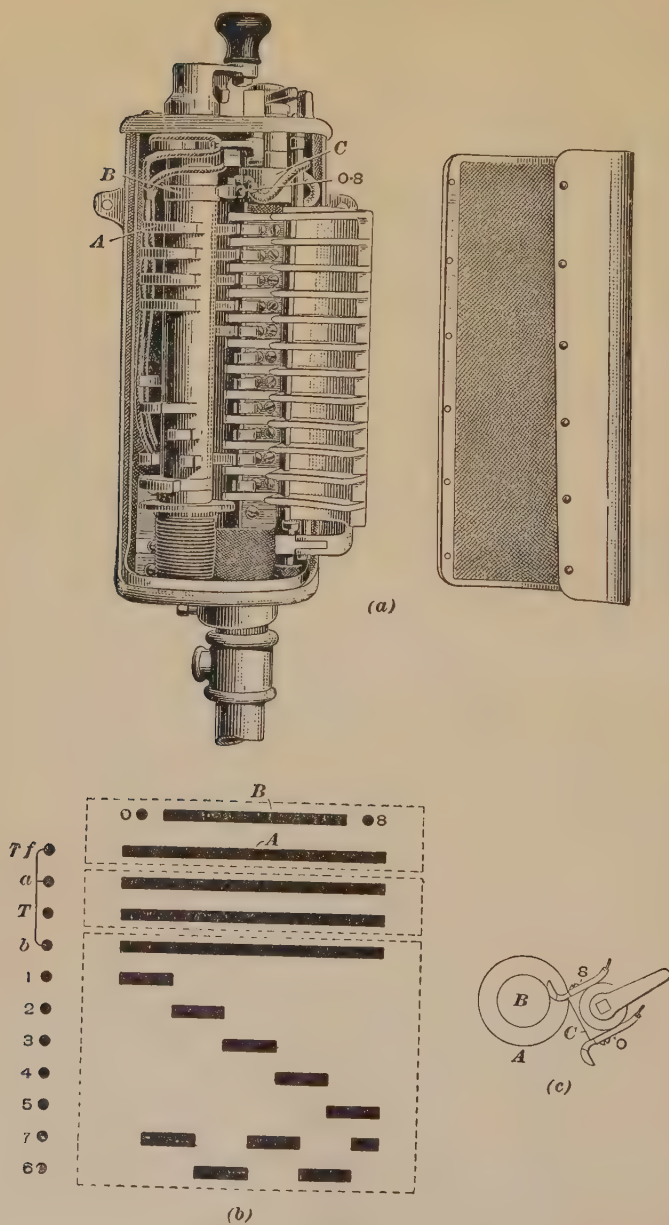
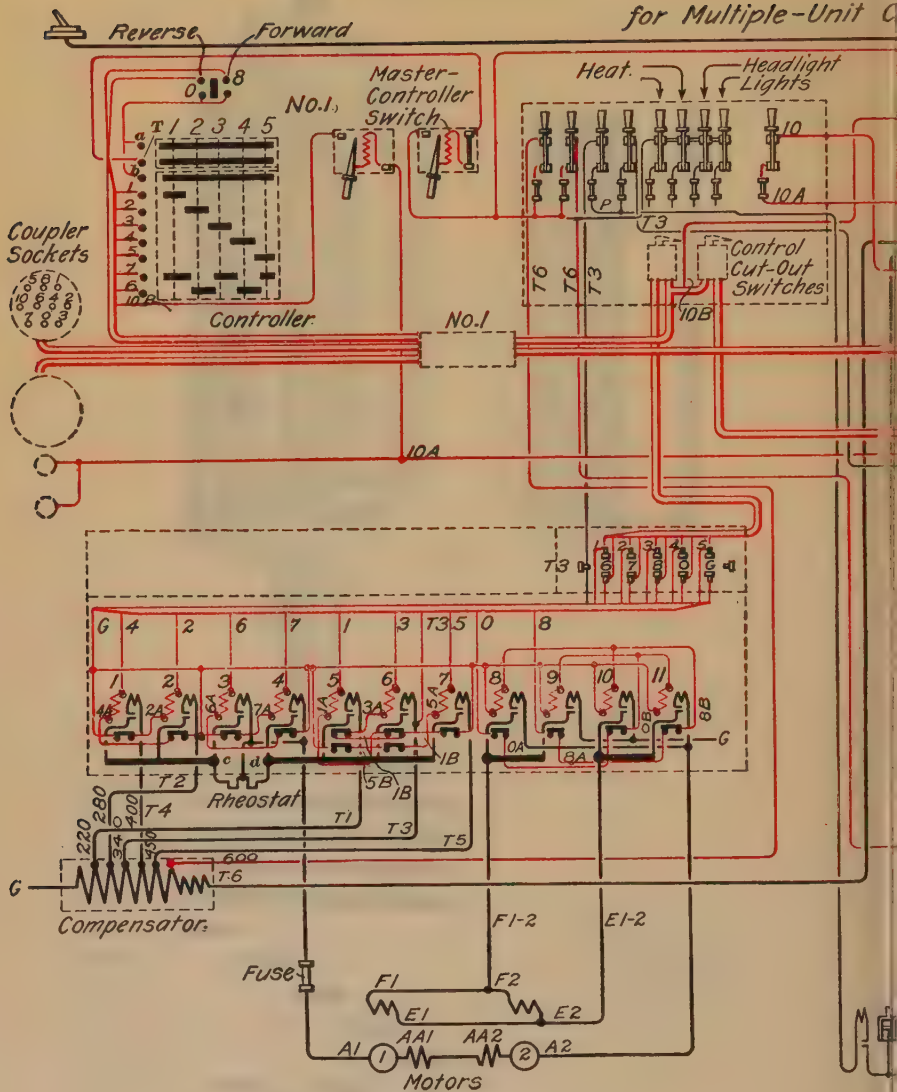


FIG. 55

CAR- for Multiple-Unit O



A:-C. Operation



accelerating section of the drum. The power section takes in the two segments opposite the fingers *T* and *a*. The reverse section consists of segment *A* opposite finger *r f*, and segment *B* opposite either finger *0* or *8*. Segments *A* and *B* are electrically connected and receive current through finger *r f*. The reverse fingers *0* and *8*, one directly behind the other, are mechanically connected to the reverse cylinder *C*, view (*a*). Either finger *0* or finger *8* may be connected to the drum segment *B* by throwing the reversing handle either to the forward or to the reverse position, as shown in view (*c*). For the forward position, finger *8* is active, and for reverse position, finger *0* is active. The coiled spring at the bottom of the case, view (*a*), serves to return the controller handle to off-position in case of emergency.

98. Car-Wiring Diagram. — A car-wiring diagram for the alternating-current operation of two master controllers connected to four motors is shown in Fig. 36. The system is duplex; that is, the control circuit, the compensator or autotransformer, and the contactors are distinct with each pair of motors. A small autotransformer, which is shown near the oil switch, provides current for the operating coil of the switch. One end of the secondary coil of this transformer is earthed near the transformer, and the other end is earthed through switch *10*—wire *10A*—left-hand master-controller switch—wire *10B*—connecting box No. 1—wire *10B*—operating coil of oil switch—earth at *G*. When switch *10* is closed, the operating coil of the oil switch closes the oil switch, and currents flow through the two compensators to earth. When the oil switch closes, the interlock under it opens, and the operating coil is earthed through a resistance. Just sufficient current flows to allow the operating coil to retain the switch in its closed position and yet not cause heating of the coil.

99. Wires are numbered or lettered alike at points where they enter and leave the multicore cable. The action of controller No. 1, Fig. 36, will be considered with the reverse cylinder, situated at the top of the controller, in the forward position; that is, with finger *8* in contact with its segment. The currents for the control circuits are obtained from tappings *T6* of the

two compensators through the two knife switches shown at the left of the group of switches. The wires of the control circuit are indicated by red lines, and the wires of the power circuit by black lines.

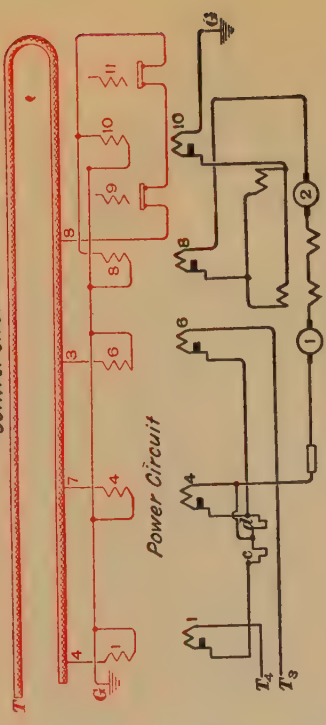
100. First Point.—On the first point, current flows from the master-controller switch to finger *T*, thence to the two drum segments, finger *a*, and to the lower right-hand finger of the reverse cylinder. Two lower reverse-cylinder fingers are shown in Fig. 36, but in the actual controller only one finger *r f*, Fig. 35 (*b*), is used. From the reverse cylinder, Fig. 36, the current path for the control of one set of motors is as follows: Finger 8—connection box No. 1—right-hand control cut-out switch—terminals 8, 8—interlock below contactor 9—wire 8*A*—interlock below contactor 11—wire 8*B*—operating coils of contactors 8 and 10 in parallel, and thence to the common earth wire *G*. From finger *a* on the master controller current also flows to finger *b*—finger 1—connection box No. 1—right-hand control cut-out switch—terminal 1—wire 1—operating coil of contactor 5—terminal 1*A*—upper interlock below contactor 6—wire 1*B*—terminals 1*B*—wire 1*B*—interlock below contactor 7—common earth wire *G*.

From finger 7 on the master controller current flows through connecting box No. 1—right-hand control cut-out switch—terminal 7—wire 7—operating coil of contactor 4—terminal 7*A*—interlock below contactor 3—earth wire *G*. The main switches 4, 5, 8, and 10 are closed by the action of their operating coils. Compensator tapping *T1* is connected to contactor 5.

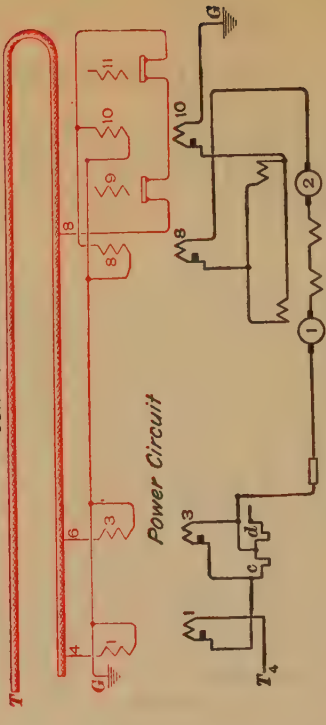
101. The two motor armatures, Fig. 36, are permanently connected in series, the compensating motor windings are connected directly in series with the armatures, and the fields of the two motors are connected in parallel. As the controller is operated, the same action is taking place in the one set of motors as in the other.

102. First Intermediate Position.—Soon after leaving the first point, Fig. 36, finger 1 drops contact, and at the same time finger 2 makes contact. When fingers 1, 2, and 7 are all active

3RD INTERMEDIATE POSITION Control Circuit



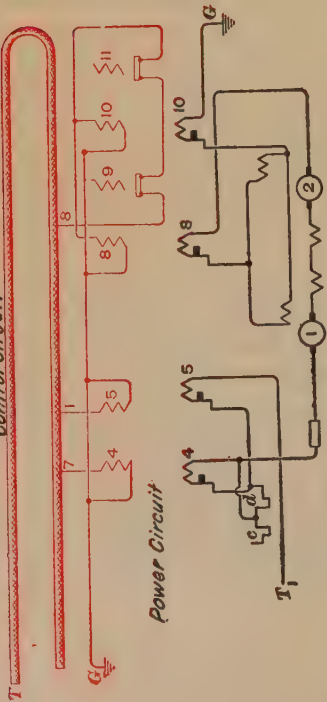
4TH POINT Control Circuit



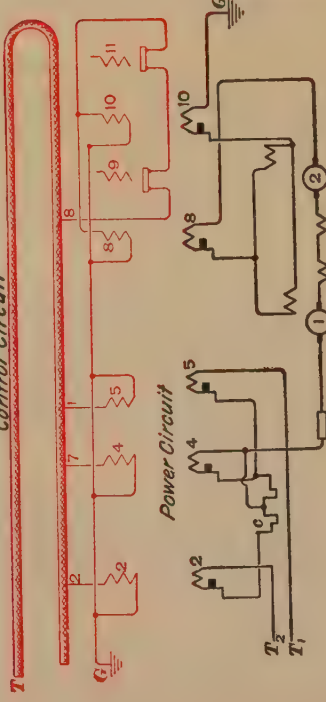
4TH INTERMEDIATE POSITION Control Circuit



1ST POINT Control Circuit

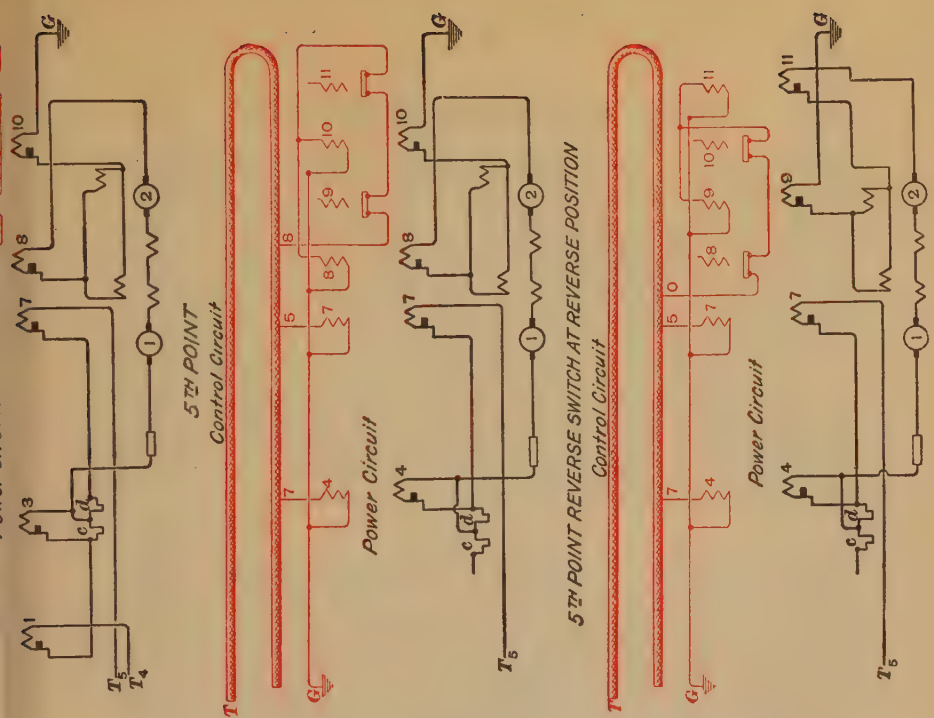
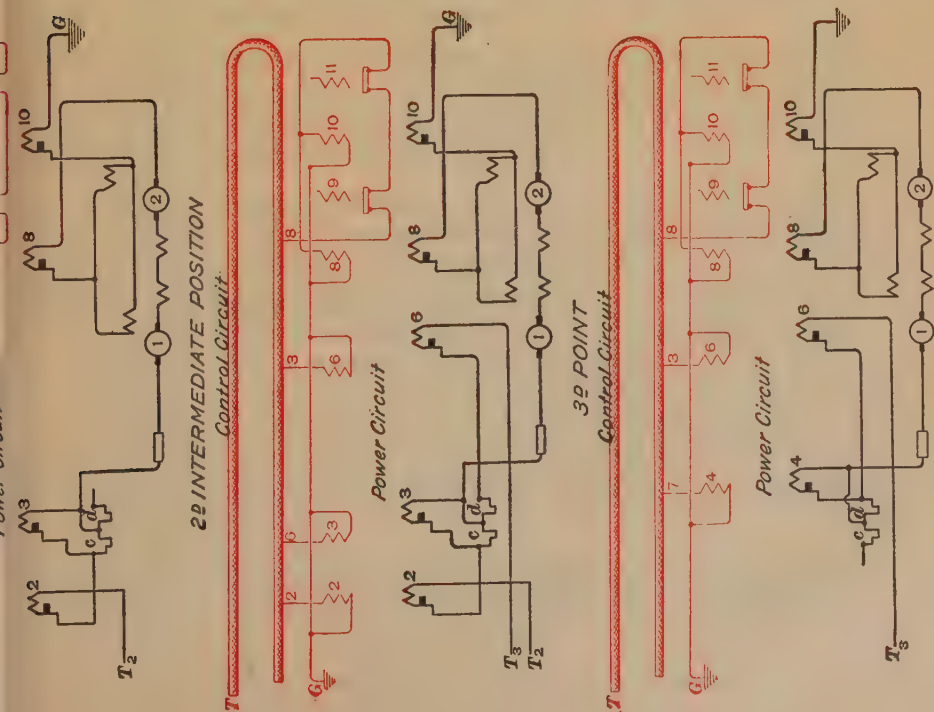


1ST INTERMEDIATE POSITION Control Circuit



2ND POINT Control Circuit





for an instant, contactors 5, 2, and 4 are closed. The motors are still connected to tapping *T1* by contactors 5 and 4, but tappings *T1* and *T2* are bridged by section *c* of the rheostat. When finger 1 drops its contact, contactor 5 opens, thus cutting out tapping *T1* and allowing all the current to flow through the tapping *T2*—contactor 2—section *c* of the rheostat—contactor 4 and wire from the centre of the rheostat, to the motors.

103. Second Point.—On the second point, finger 7 drops contact, and finger 6 makes contact with the drum segments. Contactor 4 opens and contactor 3 closes, thus cutting out section *c* of the rheostat. The motors are now connected directly to tapping *T2*.

104. Second Intermediate Position.—On the second intermediate position, finger 2 drops contact, and finger 3 makes contact. Contactor 2 opens, and contactor 6 closes. At the instant when both contactors 2 and 6 are closed, section *d* of the rheostat is bridged across tappings *T3* and *T2*. When contactor 2 opens, all the current flows from tapping *T3* through section *d* of the rheostat to the motors.

105. Third Point.—On the third point, finger 3 drops contact, and finger 7 makes contact. Contactor 3 opens and contactor 4 closes, thus short-circuiting resistance section *d* and leaving the motors connected directly to tapping *T3*.

106. Remaining Points.—The connections of the devices in the control circuits and the motor connections for the remaining points and intermediate positions are shown in Fig. 37. When moving through the intermediate positions, a rheostat section is shunted across two compensator tappings; then, the lower voltage tapping is dropped and the resistance section is left in circuit. Finally, this resistance is short-circuited, and the motors are left connected directly to the high-voltage tapping, when the controller movement to a full point is completed. On the fifth point the maximum voltage is impressed on the motors, as motor tapping *T5* is active.

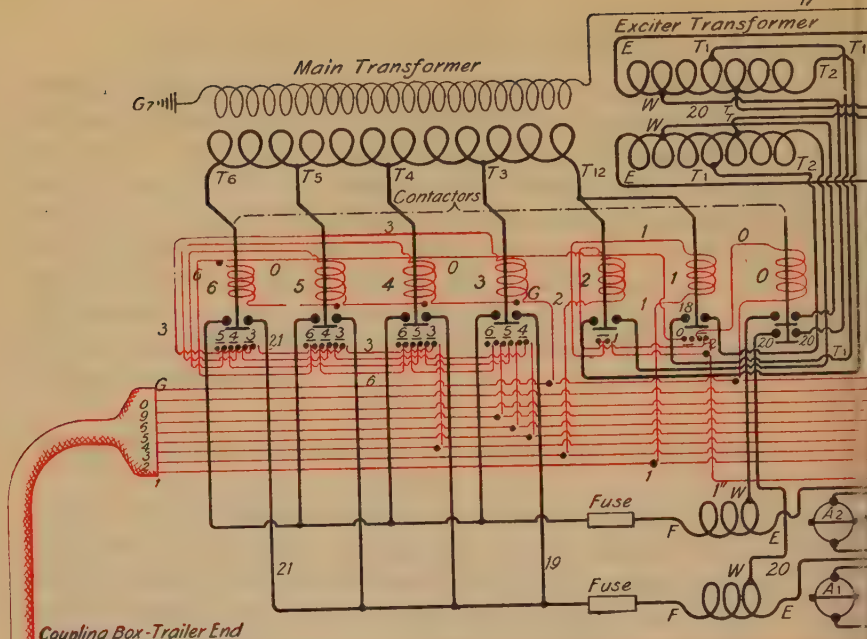
107. Operation of Reverse Cylinder.—When the reverse cylinder on the master controller, Fig. 36, is thrown to the

reverse position, contactors 8 and 10 are opened, and the lower left-hand reverse-switch finger is connected to finger 0—connecting box No. 1—right-hand control cut-out switch—terminal 0—wire 0—interlock below contactor 8—terminal 0 A—interlock below contactor 10—wire 0 B—operating coils of contactors 9 and 11 in parallel—earth wire G. Contactors 9 and 11 are closed. The connections of the armatures remain unchanged, but the field connections have been reversed, as is shown by the fifth reverse point, Fig. 37. The direction of rotation of the motors is therefore reversed.

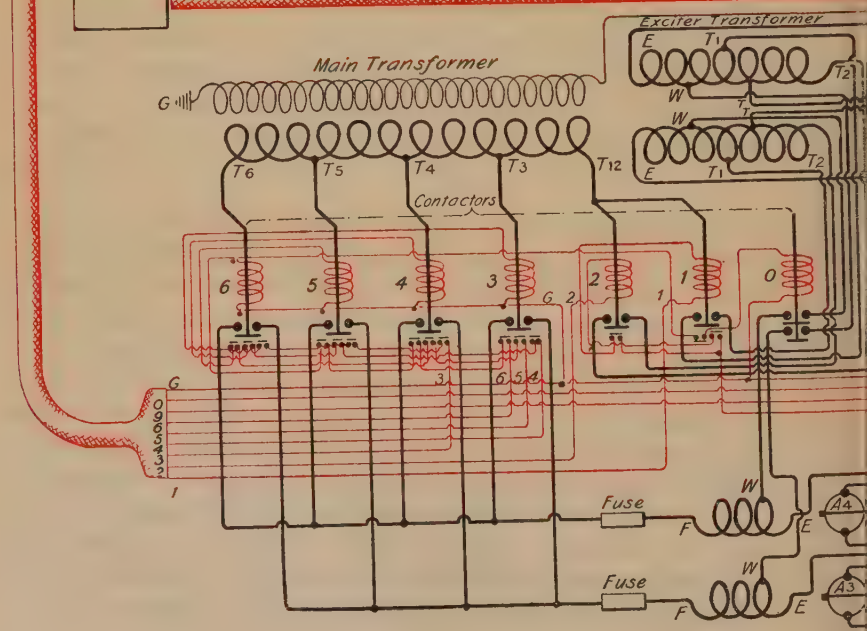
MULTIPLE-UNIT CONTROL OF COMPENSATED REPULSION MOTORS

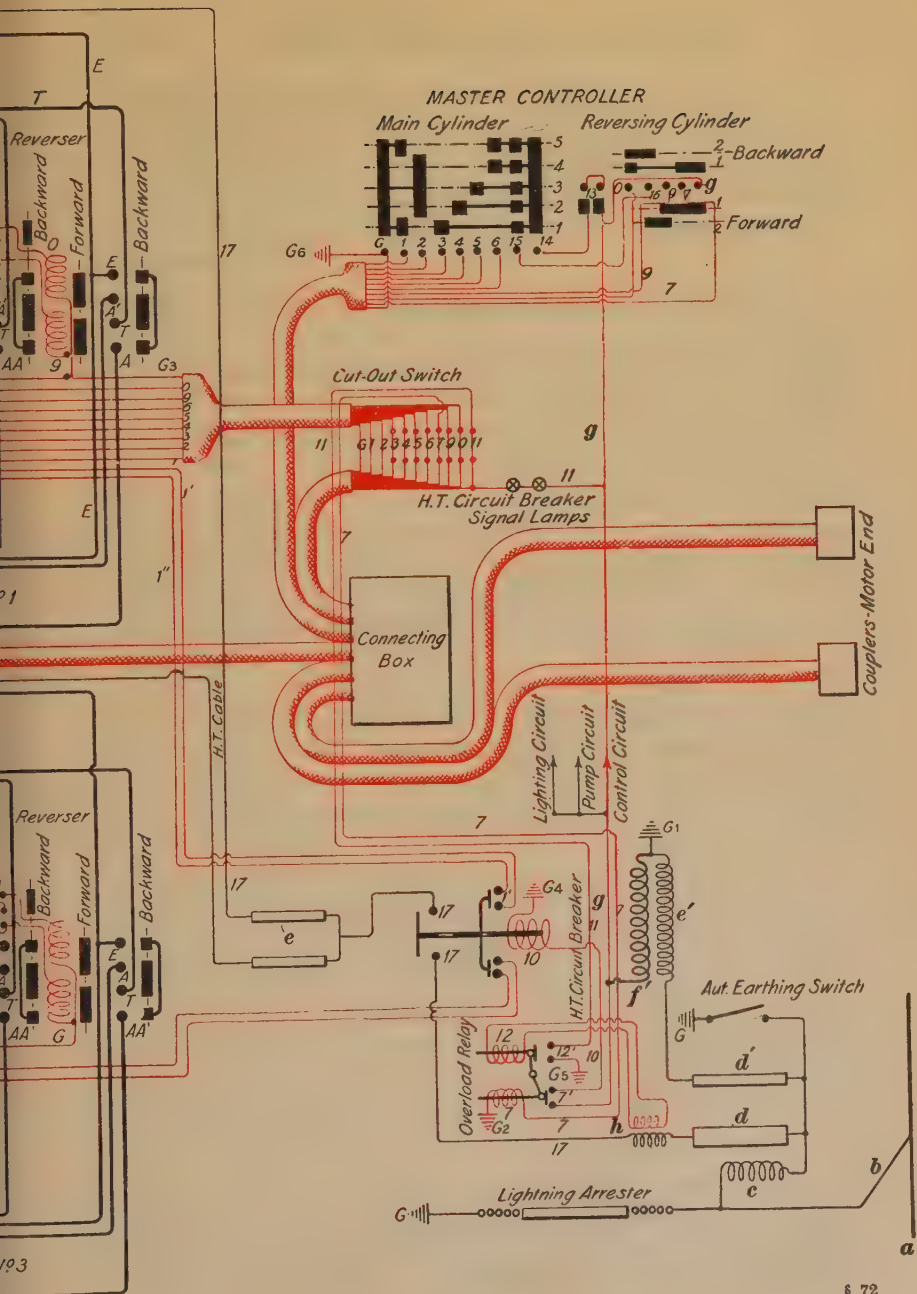
- 108. The multiple-unit system of control is applied by the Allgemeine Elektrizitäts Gesellschaft to the control of the Winter-Eichberg compensated repulsion motor. Railways operating successfully with these motors have been constructed on the Continent, and a portion of the London, Brighton, and South Coast Railway has recently been equipped with them. The master controllers used for this system are similar to those used on other multiple-unit systems, and only have to handle the small currents required to operate the contactors. The method of speed control adopted is very similar to that previously described.

109. **Car-Wiring Diagram.**—The diagram of connections for a motor coach used on the London, Brighton, and South Coast Railway is shown in Fig. 38, the operating circuits being shown in red and the main power or motor circuits in black. Each coach is fitted with four 150-horsepower motors, and the connections are so arranged that the motors can be worked through step-down transformers from a trolley wire at a pressure of 6,600 volts. The motors on the coach are operated in pairs, each motor having a separate exciter autotransformer, and each pair of motors being provided with a separate main transformer and with separate contactors. The current for operating the contactors, lighting, and heating is furnished at a pressure of 300 volts by the secondary of a small auxiliary step-down transformer, the



Coupling Box-Trailer End





primary of which is connected to the 6,600-volt circuit as soon as the collector bow is placed in contact with the trolley wire. All the contactors are fitted with interlock contacts, so that the contactors can only close in the proper order. The master controller has both main and reversing cylinders operated by separate handles.

110. Operation of Main Circuit-Breaker and Reverser.—Preparatory to starting the coach, the collector bow is raised into contact with the trolley wire. Current then flows in the control circuit, Fig. 38, from the trolley wire *a*—collector *b*—choking coil *c*—high-tension fuse *d'*—primary *e'* of auxiliary transformer to earth at *G1*. The auxiliary transformer is thus energized, and the secondary *f'* is ready to supply current for the operating circuits. To start the coach in a forward direction, the reversing cylinder of the master controller is placed in forward position *1*. Operating current then flows as follows: Secondary *f'*—wire *g*—contact finger *g* on reversing cylinder—contact segment on reversing cylinder—

contact finger 7—wire 7—connecting box—blade 7 of cut-out switch—wire 7—operating coil 7 of overload relay—earth at <i>G2</i> .	contact finger 9—wire 9—connecting box—blade 9 of cut-out switch—wire 9—contact finger 9 of reverser—operating coil 9—earth wire <i>G3</i> .
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The energizing of operating coil 7 of the overload relay causes it to close the contacts 7', which are held closed mechanically. Coil 10 of the high-tension circuit-breaker is energized through the following circuit: Secondary *f'*—wire *g*—contacts 7'—wire 10—operating coil 10—earth at *G4*. The high-tension automatic circuit-breaker then closes. Owing to operating coil 9 on the reverser being energized, the reverser is pulled to the forward position, so that the segments marked *forward* make connection with the contact fingers.

111. The reversing cylinder on the master controller, Fig. 38, is then moved to forward position *2*; this disconnects contact finger 7, and therefore operating coil 7 on the overload relay is de-energized, leaving the overload relay free to be operated by

coil 12, which is connected to the secondary of the current transformer *h*. When the main high-tension current passing through the primary of current transformer *h* reaches too great a value, coil 12 operates the overload relay, which opens contacts 7', and thus de-energizes operating coil 10 of the high-tension circuit-breaker. The circuit-breaker is then opened by the action of a spring. A circuit is also provided through the high-tension automatic-switch signal lamps as follows: Secondary *f'*-wire *g*-wire 11-signal lamps-blade 11 of cut-out switch-wire 11-contacts 12' on overload relay-earth at *G5*. The signal lamps then light, indicating that the circuit-breaker has opened.

In the second forward position of the reversing cylinder of the master controller the supply to operating coil 9 on the reverser is continued, when the main cylinder of the master controller is in one of the working positions; the path is from wire *g*, through contacts 13 and contact fingers 14, 15, and 16, on the master controller, to wire 9. The reverser is thus held in the forward position.

112. Operating Circuits, First Position of Controller.—When the main cylinder of the master controller, Fig. 38, is moved to the first position, the operating current for one reverser and group of contactors flows as follows: Secondary *f'* of auxiliary transformer-wire *g*-contacts 13-contact finger 14-contact segments on main cylinder of master controller-contact finger 3-connecting box-blade 3 of cut-out switch-wire 3-interlock 3 of contactor 4-interlock 3 of contactor 5-interlock 3 of contactor 6-wire 3-operating coil of contactor 3-earth wire *G3*. Contactor 3 closes.

Owing to the reverser being in the forward position, operating current flows from contact finger 9 on reverser-contact segment-contact finger 1' on reverser-wire 1'-auxiliary contacts 1' on high-tension circuit-breaker-wire 1''-interlock 1 of contactor 2-wire 1-operating coil of contactor 1-wire 1-blade 1 of cut-out switch-connecting box-contact finger 1 on main cylinder of master controller-segments of master controller-contact finger *G*-earth at *G6*. Contactor 1 then closes. Thus, in the first position of the master controller, contactors 1 and 3 are closed.

113. Power Circuits, First Position. — The main power or motor circuit for one half of the equipment in Fig. 38, consisting of main transformer, exciter autotransformers, and pair of motors, is then as follows, the circuit for the other half of the equipment being exactly similar: Overhead line *a*—collector bow *b*—choking coil *c*—fuse *d*—primary of current transformer *h*—wire 17—contacts 17 on high-tension circuit-breaker—isolating switch *e*—wire 17—primary of main transformer—earth at *G7*. The main transformer is thus energized. Contactors 1 and 3 are closed so that the secondary circuits through motor No. 1

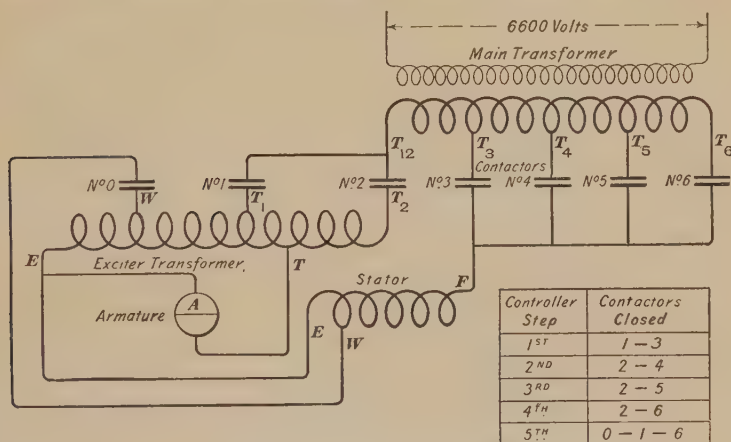


FIG. 39

are as follows: Tapping *T12* on secondary of the main transformer—contact 18 of contactor 1—wire *T1*—tapping *T1* of exciter autotransformer—winding of autotransformer from *T1* to *E*—wire *E*—field *EF* of motor No. 1—fuse—wire 19—contact of contactor 3—tapping *T3* on main transformer. This circuit does not include the armature of the motor, the circuit through the armature being from wire *E*—finger *E* on reverser—reverser segment—finger *A'*—armature *A1*—finger *A*—finger *T*—wire *T*—tapping *T* on exciter autotransformer. The auxiliary winding *EW* of the stator of the motor is in series with the main winding for all positions of the controller except the final running position.

The power circuit outlined in the preceding paragraph may be more easily traced by reference to Fig. 39, which shows only the connections for the power circuit for a single motor. Corresponding parts and tappings are lettered the same in both Fig. 38 and Fig. 39. In Fig. 39 is given a list of the controller steps or positions and the contactors which are closed for each step.

114. Second, Third, and Fourth Positions of Controller.—In the second position of the controller the earth connection to the operating coil of contactor 1, Fig. 38, is broken, so that contactor 1 opens, and in doing so closes interlock 2 beneath it. Contactor 2 closes, its earth connection being completed through interlock 2 and contact finger 2 on the master controller. The operating coil of contactor 3 is de-energized because finger 3 on the master controller breaks contact with the segment, and as finger 4 makes contact, contactor 4 is energized; hence contactor 3 opens and 4 closes. Thus, contactors 2 and 4 are closed in the second controller position, and the power circuits can be followed by reference to Fig. 39. If the circuits are traced out in Fig. 38 for the third and fourth controller positions, it will be found that in the third position contactors 2 and 5 are closed, and in the fourth position contactors 2 and 6 are closed. The effect of the various changes of connections is to cut successively into circuit the sections $T12-T3$, $T12-T4$, $T12-T5$, and $T12-T6$ of the main transformer, thus increasing the E.M.F. applied to the motor terminals and causing the speed to increase. These changes may be followed by referring to the simplified diagram.

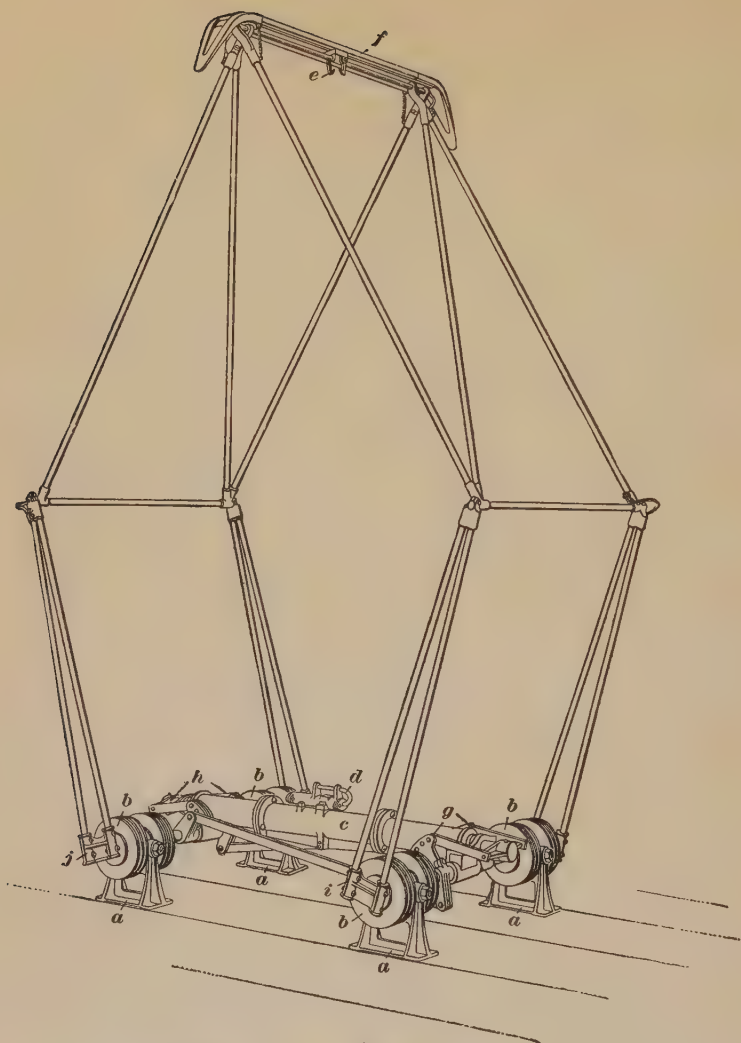
115. Fifth Controller Position.—In the fifth and final running position, the operating coils of contactors 1 and 6, Fig. 38, are energized through circuits completed on the main cylinder of the master controller. When contactor 1 closes, the interlock 0 underneath it is also closed. This provides a path for operating current to pass from wire 6 (near contactor 6) to wire 0, through interlock 0 beneath contactor 1, to wire 0 and thence to operating coil of contactor 0, which closes. Thus, contactors 0, 1, and 6 are closed, so that the maximum E.M.F.'s due to both the main and exciter transformers are impressed on the motor.

The main secondary circuit for motor No. 1 is then as follows : Tapping *T12* on main transformer—contact *18*—wire *T1*—tapping *T1* on exciter autotransformer—winding from *T1* to *E*—wire *E*—field winding *EF* of motor No. 1—fuse—wire *21*—contact of contactor *6*—terminal *T6* of main transformer. The armature of motor No. 1 is connected from terminal *E*—finger *E* on reverser—finger *A'*—armature *A1*—finger *A*—finger *T*—wire *T*—tapping *T* on exciter autotransformer. The auxiliary stator winding *EW* of the motor is connected by means of wire *20*—contacts *20* of contactor *0*—wire *20* to tapping *W* on the exciter autotransformer. The E.M.F. impressed on the auxiliary winding *EW* by the transformer windings between *W* and *E* sends a current through the auxiliary stator coils of the motor and aids in securing sparkless commutation at high speed. The main high-tension circuit is provided with a lightning arrester, and with an automatic earthing switch, by which the whole of the high-tension apparatus on the motor coach is connected to earth when it is necessary to execute repairs.

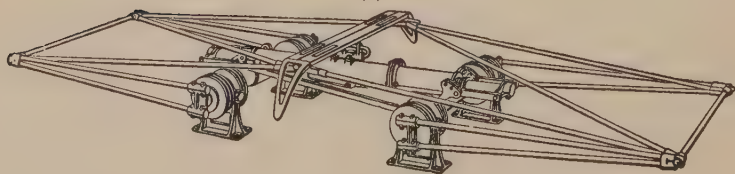
CURRENT COLLECTORS

PANTOGRAPH TROLLEY

116. Construction of Pantograph Trolley.—In single-phase railway work, as in three-phase work, current is nearly always collected from the overhead conductor by means of some form of bow collector. A Westinghouse **pantograph trolley** is shown in its raised position in Fig. 40 (*a*). The trolley is secured to the top of the locomotive or coach by the feet *a*, which are insulated from the other parts of the frame by the massive insulators *b*. The main operating cylinder *c* contains pistons which are connected by means of crossheads to levers *g* and *h*. A trolley lock or latch cylinder *d* is placed above the main cylinder. A hook *e* on the lower side of contact shoe *f* engages with the latch when the trolley is in its lowered position, as in view (*b*). The main contact shoe consists of a strip of galvanized iron, which is usually made about 6 inches wide, so as to have a large surface in contact with the wire. The upper surface of the shoe is furnished with



(a)



(b)

FIG. 40

grooves in which grease is placed; this acts as a lubricant, and reduces the friction between the shoe and the wire. It is customary to zigzag, or stagger, the trolley wire slightly, so that the wear on the conducting surface of the shoe will be distributed. The shoe is so long that it is impossible for it to leave the wire under normal conditions.

117. Operation of Pantograph Trolley.—The pantograph is worked by means of compressed air, supplied through pipes connected to the main cylinder and to the latch cylinder. The pantograph is normally held in a raised position against the wire by compression springs *k*, Fig. 41 (*a*). These springs force

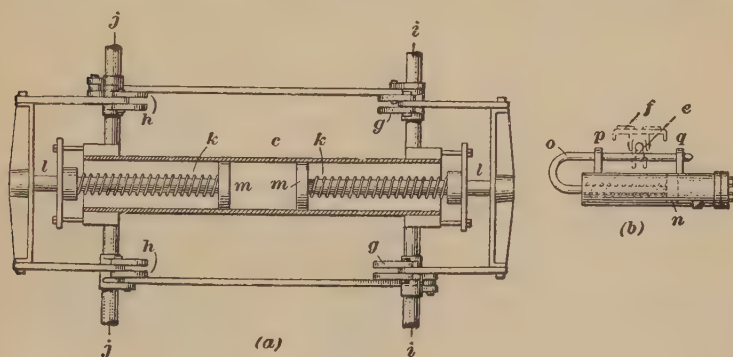


FIG. 41

piston rods *l* and pistons *m* toward the centre of the main cylinder *c*, thus causing short levers *g* and shaft *i*, Figs. 40 (*a*) and 41 (*a*), to rotate in a counter-clockwise direction, and levers *h* and shaft *j* to rotate in a clockwise direction. The arms attached to the shafts are forced upwards, and the shoe is pressed against the conductor wire.

118. In order to lower the collecting bow, compressed air is allowed to flow into the centre of the main cylinder. The pistons *m*, Fig. 41 (*a*), are forced outwards, shaft *i* is rotated in a clockwise direction, shaft *j* is rotated in a counter-clockwise direction, and the trolley is lowered to the position shown in Fig. 40 (*b*). When in this position, the hook *e*, Fig. 40 (*a*), which is divided into two parts, automatically catches round a projection

from latch-cylinder piston *n*, Fig. 41 (*b*), which forms latch *o*, now in its closed position. A spring in the latch cylinder normally keeps piston *n* in such a position that the latch *o* extends through lugs *p* and *q* on the cylinder, and when the trolley is down, through hook *e* on the contact shoe *f*. The compressed air is then turned off from the main cylinder, and the latch holds the collecting bow down. When it is desired to raise the trolley, air is momentarily admitted into the latch cylinder, which moves piston *n* and latch *o* so as to release hook *e*. The main cylinder springs then raise the trolley. The air in the main cylinder between pistons *m*, Fig. 41 (*a*), acts as a buffer as the pistons are forced toward each other, thus preventing too sudden action of the springs.

OERLIKON COLLECTOR

119. Construction of Collector.—The type of collector adopted by the Oerlikon Company of Zurich is shown in Fig. 42. This

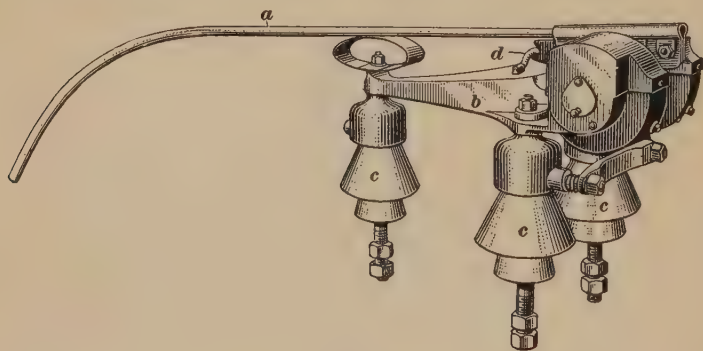


FIG. 42

type of collector differs considerably from collectors of the bow and pantograph varieties in that it will collect current from the side, upper, or lower surfaces of the conductor wire as may be required. The contact surface is a replaceable brass strip fitted to a curved steel tube *a*, which can rotate about an axis at one end through 180°. It is pressed against the conductor wire by a helical spring, which is not shown. The framework *b* of the collector is supported on the porcelain insulators *c*, which

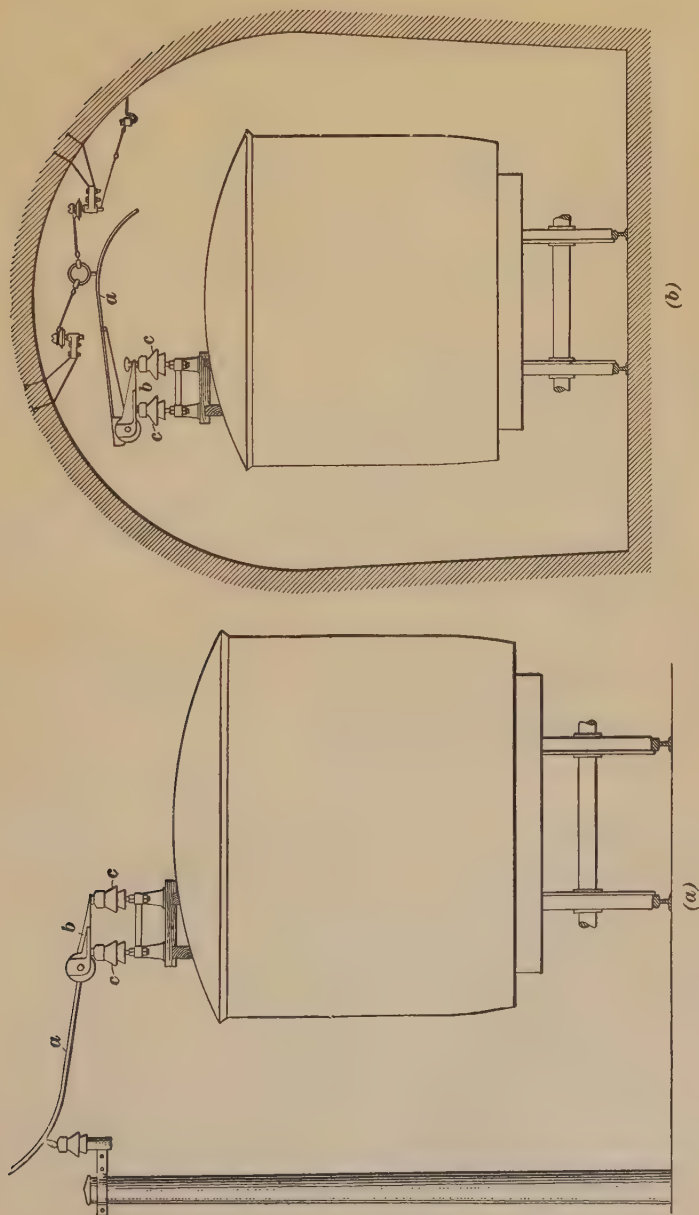


FIG. 43

are bolted to a wooden base fixed to the roof of the locomotive or motor coach. The collector is controlled from the driver's cab by means of a lever, and can be held in the position shown by the catch *d*.

120. Action of Collector.—The two extreme positions of the collector rod are shown in Fig. 43 (*a*) and (*b*), which is lettered similarly to Fig. 42. View (*a*) shows the position of the collector rod when taking current from the upper surface of the conductor, and view (*b*) when collecting from the lower surface in a tunnel. When the collector rod is taking current from the lower surface of the conductor, the weight of the rod opposes the action of the spring, but the collector is so designed that the spring exerts its maximum force in this position. When the contact rod is turned through 180° , and is collecting current from the top of the conductor, the force of the spring is a minimum, and is aided by the weight of the rod. By this means an almost uniform pressure of about $6\frac{1}{2}$ pounds is obtained on the overhead wire for all positions of the collector.

SUSPENSION OF OVERHEAD CONDUCTOR

SINGLE-CATENARY CONSTRUCTION

121. Use of Catenary Suspension.—In order that the overhead conductor may successfully stand the heavy and continual wear to which it is subjected in high-speed railway work, and in order that the insulation may remain sound at the very high pressures used, a special construction which keeps the conductor at practically the same height between main supports is adopted. A trolley wire suspended in the ordinary way sags down between supports in the form of a curve, called a *catenary*. In the **single-catenary construction**, such as is shown in Fig. 44, a messenger, or catenary cable, *a*, usually of stranded steel wire, is supported on insulators on the bracket arms *d*. Short metallic *droppers*, or *hangers*, *c* are used to connect the messenger cable to the hard-drawn copper trolley wire *b*. The hangers are of

such relative lengths and are sufficiently close together that the trolley wire *b* does not sag any appreciable amount. The messenger cable passes through earthed metal loops *f* on the bracket arms, so that in case of breakage the whole section will be earthed.

In some installations the method of supporting the catenary construction shown in Fig. 45 is used. The bracket arm *a* carries the insulator *b*, which has a grooved top in which the catenary cable *c* is placed. The trolley wire *d* is supported below the arm by the hangers *e*.

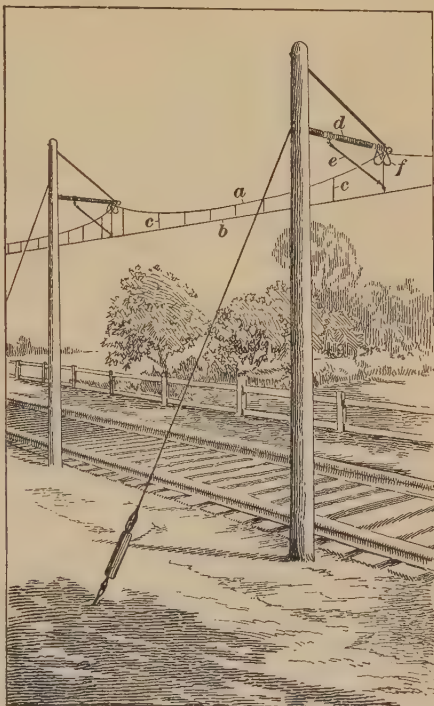


FIG. 44

122. Steady Strain Bracket.

—On curves of large radius and at intervals of about 440 feet on straight track, wooden push-off, or pull-off, rods *e*, Fig. 44, are used to keep the catenary construction in an upright position. These wooden rods are fitted at the ends with metal caps, and are attached to porcelain insulators on the bracket arms. A bracket equipped with a push-off or pull-off of this description is known as a **steady-strain bracket**. The details of construction of one type of steady-strain bracket are shown in Fig. 46. The bracket arm *a*, which may consist of a steel tube or T iron, is bolted to the pole *b*, and is supported by a tie-rod *c* and brace *d*. A tubular corrugated porcelain insulator *e* on the bracket arm is encircled by a clip which carries the catenary cable *f*. The trolley wire *g* is suspended from the catenary by the dropper *h* and is held in place

by the push-off *t*, which is attached to the brace *d* by the porce-

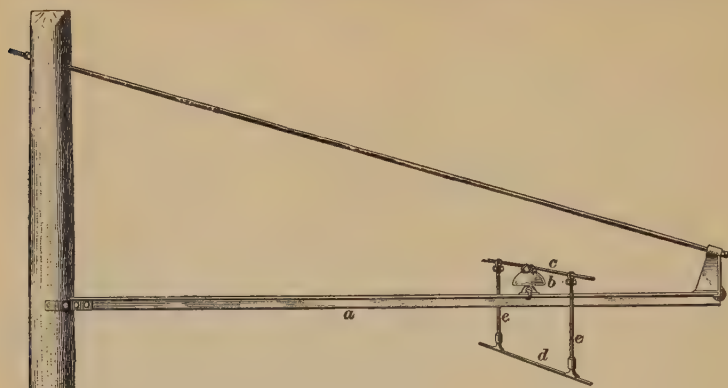


FIG. 45

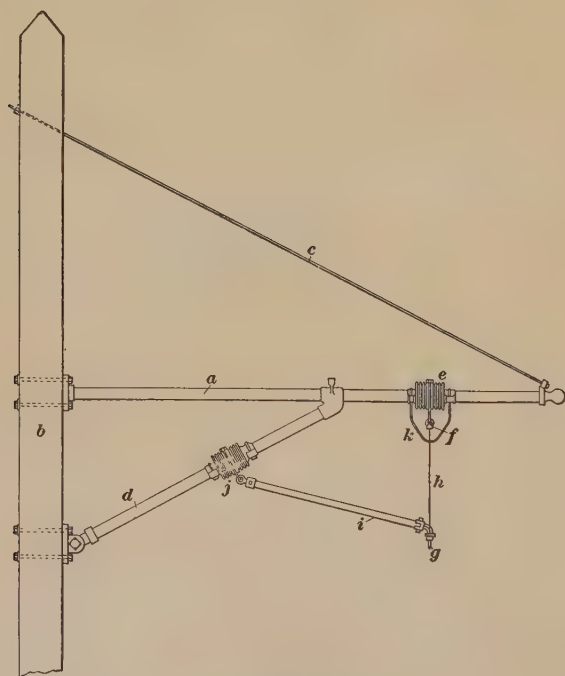


FIG. 46

lain insulator *j*. The earthing loop is shown at *k*. The construction of the tubular porcelain insulator *e* with the earthing

loops is shown in Fig. 47, view (a) being a side elevation and view (b) an end elevation. The bracket arm *a* is surrounded by

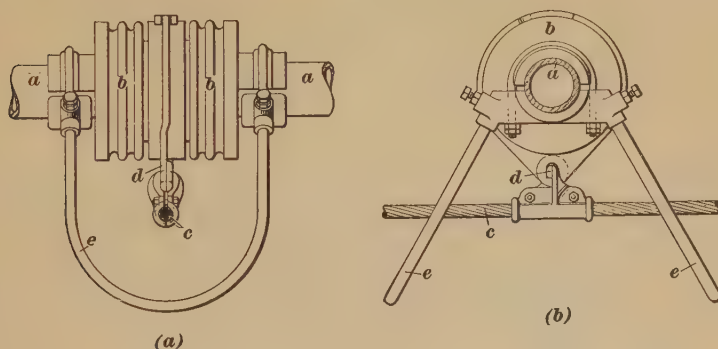


FIG. 47

the porcelain insulator *b*. The catenary *c* is supported by the clip *d* which encircles the insulator *b*. The earthing loops *e* are clamped to the bracket arm *a*, as shown.

123. Hangers.—One type of hanger used to suspend the trolley wire from a single catenary cable is shown in Fig. 48. The catenary cable is encircled by a clamp *a*, and is connected by the steel tube or rod *c* to an ear *b* which grips the trolley wire. The length of the tube or rod is made to suit the position in which the hanger is to be used



FIG. 48

DOUBLE-CATENARY CONSTRUCTION

124. Arrangement of Double-Catenary Cables. For railways on which traffic is heavy two catenary cables, as shown at *a*, Fig. 49, are used to support the trolley wire *b*. The hangers are triangular in form, the trolley wire being at the lowest point. The catenary construction is usually suspended from steel lattice girder bridges, known as **gantries**, the catenary cables being supported on heavy porcelain insulators mounted on the top of the cross-girder of the gantry. At intervals anchor bridges are erected, at which one section of overhead work is terminated,

and a new one started. The catenary cables on both sides of the anchor bridge are connected to strain insulators and the trolley wires to a section insulator ; the ends of the trolley wire are connected together by a switch mounted on the girders of

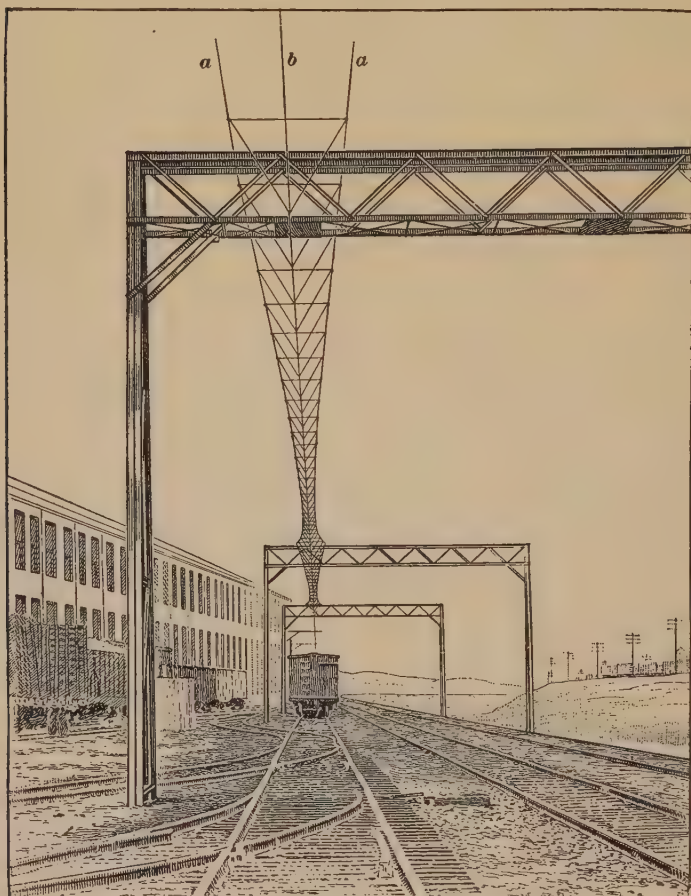


FIG. 49

the bridge, so that the two sections can be disconnected from each other and from the current supply when desired. For single-track railways the cables are sometimes carried by single posts and bracket arms, but this construction is not recommended.

125. Disadvantages of Rigid Suspension.—The form of double-catenary construction just described is too rigid. In one case where the pantograph collector was used its steel bar, owing to the pitching of the locomotive, gave the trolley wire a series of hammer blows, with the result that the conductor was roughened by wear and excessive sparking ensued. Also, the section of the copper wire was soon reduced by wear. Since no provision was made for the expansion of the wire, the slack due to the high temperature was carried in a loop by the collector until a hanger was reached, when a bad kink was formed in the wire; this kink eventually resulted in a fracture. These difficulties have been overcome by the arrangement of the conductors shown in Fig. 50. The catenary cables *a* support the hard-drawn copper

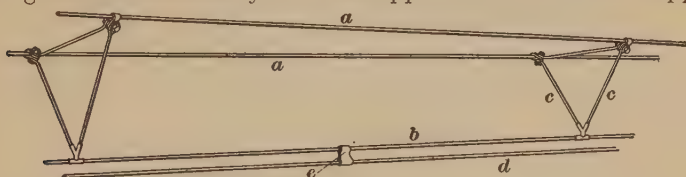


FIG. 50

trolley wire *b* in the usual way by means of hangers *c*. An extra working conductor *d* made of steel is clamped to the trolley wire midway between supports by metal clips *e*. The steel cable thus receives the wear and the copper trolley wire acts as a feeder.

On the London, Brighton, and South Coast Railway each catenary is separately erected and is adjustable by means of two turnbuckles in each span. The droppers, if longer than 3 feet 6 inches, consist of solid rods loosely jointed in the middle by loops. These rods are fixed together at the lower ends by clips, which also hold the trolley wire. Droppers of a shorter length than 3 feet 6 inches have only a loop at the bottom end; these loops are threaded into another loop held by the trolley-wire clip. By these means flexibility is secured.

FITTINGS FOR CATENARY SYSTEMS

126. Push-Offs.—Two types of push-offs, which may be used with either single or double catenary systems, are shown in Fig. 51. That in view (*a*) consists of a stout rod *a* of some

hard wood, such as hickory, fitted with a cap *b* hinged to the casting *c*, which is attached to the pole or bracket arm. The rod is attached to the trolley wire by the cap *d*. The push-off shown in view (*b*) is of the same type and is similarly lettered, but is provided in addition with porcelain and mica insulation, which is shown in detail in view (*c*). The cap at the bracket-arm end of the push-off is provided with a bolt *e*, which passes

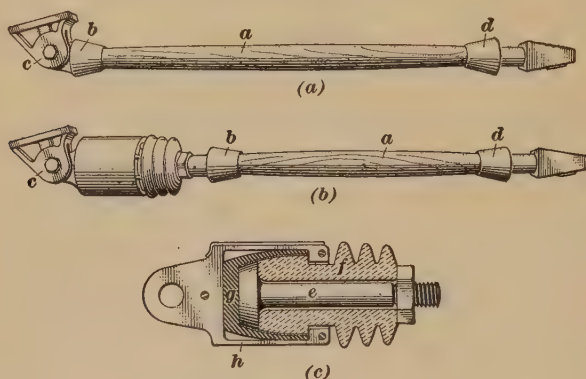


FIG. 51

through the corrugated porcelain insulator *f*. The head of the bolt is protected by the insulating cap *g*, which is made of moulded mica. The head of the bolt, the mica cap, and part of the porcelain insulator are enclosed in a malleable-iron case *h*. Under working conditions, all the insulation is under compression.

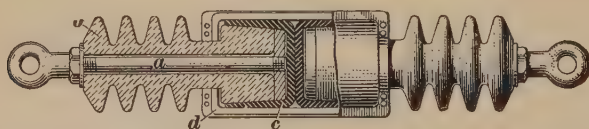


FIG. 52

Even if all the porcelain should break and fall out of the case, the head of the bolt *e* is too large to pass through the opening in case *h*, so that the push-off will not collapse.

127. Pull-Offs.—A well-designed type of pull-off or strain insulator is shown, half in section, in Fig. 52. A bolt *a* passes through the centre of the porcelain insulator *b*, the head of the

bolt being insulated by the moulded mica cap *c*. Both halves

of the pull-off are encased in a malleable-iron casing *d*. Insulators of the rod type shown in Fig. 51 are also used as pull-offs.

A good method of using an ordinary tubular corrugated porcelain insulator in connection with a pull-off is shown in Fig. 53 (*a*). The clip *a* is for a single catenary cable, and is connected through the hanger *c* to the trolley wire at *b*. Pull-off wires *d*, *e*, attached to the top and bottom of the hanger, are connected to the single pull-off wire *f*. The other end of wire *f* is fixed to the clip *g* which encircles the corrugated porcelain insulator *h*. This insulator is attached by means of a bolt passing through it to brackets on the pole *i*. The detail of the hanger *c* used for this construction is shown in view (*b*). It will be noticed that the ear *b*, to which the trolley wire is attached, is extra long, and that two grooves *c'*, *c'* are provided for attaching the pull-off wires.

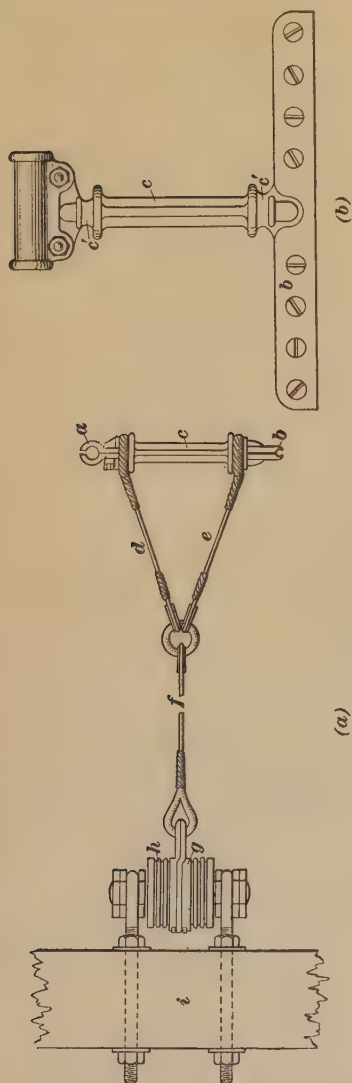


FIG. 53

128. Catenary Insulator.

One type of insulator used to support the catenary cable is shown in Fig. 54. The outer porcelain petticoat *a* is about 5 inches in diameter, and is

cemented to the inner porcelain petticoat *b*. This is in turn supported on a very deep cup *c* of moulded mica, a packing *d* of spun yarn or other material being placed between the porcelain petticoat *b* and mica cup *c*. The mica cup *c* is carried on a malleable-iron pin *e*, to which it is attached by means of cement.

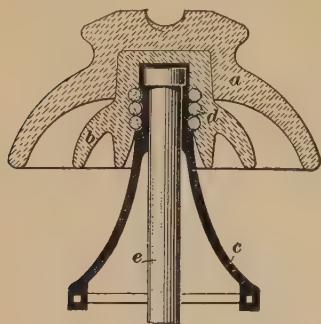


FIG. 54

129. Section Insulators.—Section insulators are used in overhead work of the catenary type, as in other types of railway and tramway work, to divide the line into separate sections.

The insulators are generally so arranged that they can be short-circuited by means of a high-tension connecting switch placed at the top of the pole supporting the overhead work, and operated by a long wooden rod. A simple type of section insulator is shown in Fig. 55. It is fastened to the

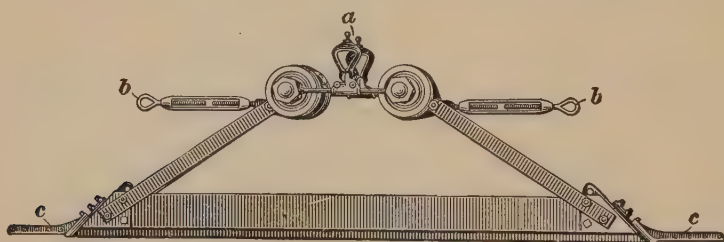


FIG. 55

T-iron support or bracket arm by means of clamps *a*. The catenary cable is attached to the turnbuckles *b* and the trolley wires of the two sections of line to the ears *c*. The running surface between the ears *c* is a strip of hardwood, as in other section insulators. In some cases, section insulators are dispensed with, the end of the trolley wire of one section being suspended parallel to, and about 16 inches distant from, the end of the trolley wire of the other section. The wires are parallel for some distance, but are carefully insulated from each other

130. Deflector Wires.—In order to ensure that the collector bow will pass over the junction of the main and turnout trolley wires, at turnouts and cross-overs, **deflector wires** are placed in the angle formed by the two trolley wires, as shown in Fig. 56.

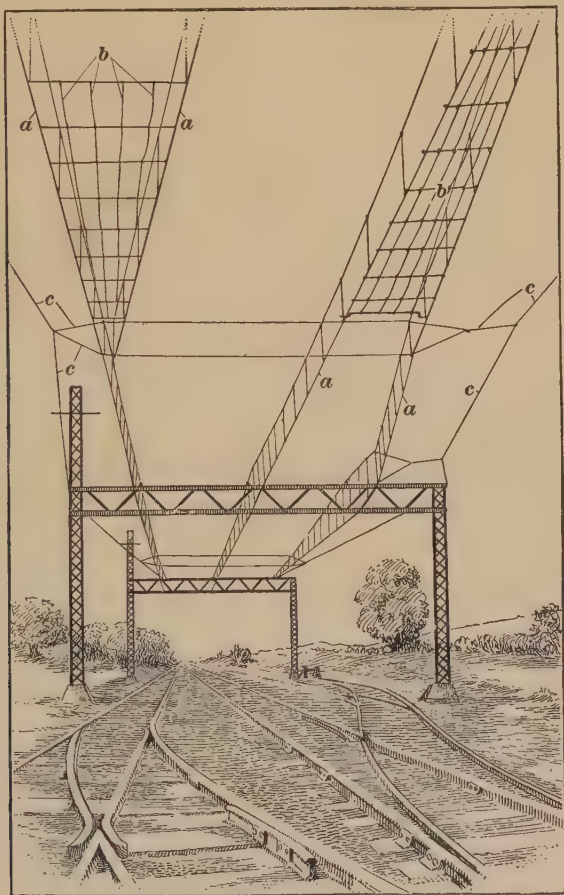


FIG. 56

The trolley wires *a* are connected together by a system of cross wires which carry the deflector wires *b*. The trolley wires are maintained in their proper positions with respect to the track by the pull-off wires *c*. The trolley wire under which the collector

bow is moving is elevated slightly above the other trolley wire by the pressure of the bow, so that, were it not for the deflector wires and the method of mechanically connecting the trolley wires together, which to a certain extent equalize the elevation of the wires, the bow might catch in one of the wires as it approaches a junction.

SIEMENS CATENARY SUSPENSION

131. Arrangement of Cables.—A form of construction installed by the Siemens-Halske Company on a number of railways on the Continent is shown diagrammatically in Fig. 57. The catenary cable *a* is hung on insulators in the usual way from anchor

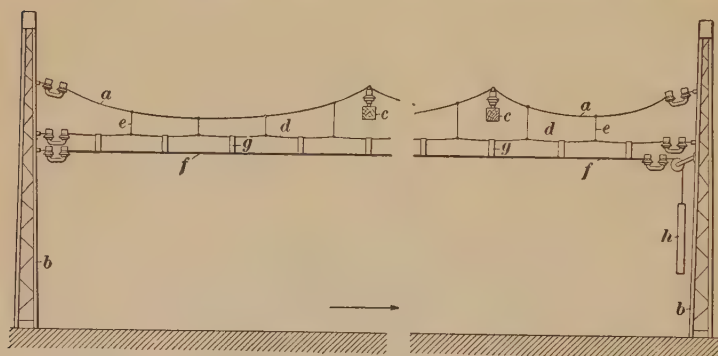


FIG. 57

poles *b* and gantries *c*. From the catenary an auxiliary cable *d* is suspended by means of hangers *e*. The trolley wire *f* is carried by the auxiliary cable *d* by means of special clips *g*. These

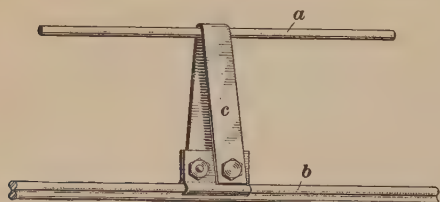


FIG. 58

clips are firmly fixed to the trolley wire, but are free to slide on the auxiliary cable *d*, as shown in Fig. 58, where *a* is the auxiliary wire, *b* the trolley wire, and *c* is the clip. The trolley wire is kept under a constant tension by means of a heavy weight *h*, Fig. 57, which is attached to one end by a chain passing over a

suitable arrangement of pulleys. The trolley wire is thus free to expand, and all slack is taken up by the weight. The direction

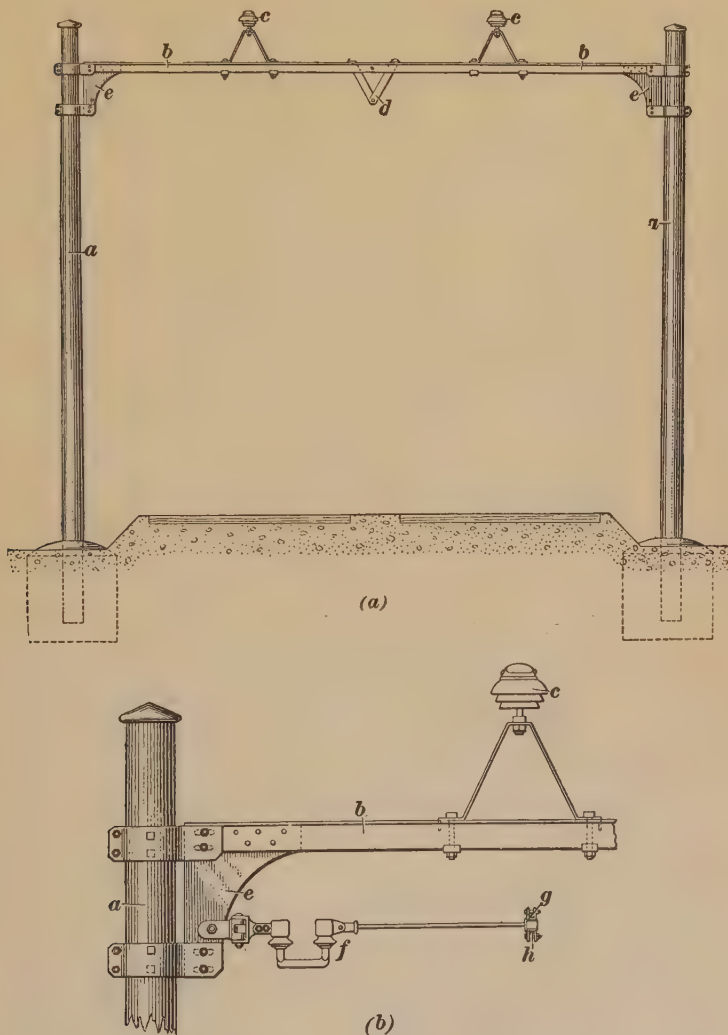


FIG. 59

of traffic, as indicated by the arrow, is such that the collector bow wipes any slack along toward the weight.

132. Construction of Gantry.—The gantries used to support the Siemens catenary construction between anchor poles are arranged as shown in Fig. 59 (a). The poles *a* are of wood, and the cross-pieces *b* are of double angle iron, and are bolted to circular clips embracing the poles. The catenary insulators *c* are attached to brackets on the top of the angle irons *b*. The projection *d* and web *e* are used for the attachment of pull-offs or push-offs, as shown at *f*, view (b), which gives the detail of the construction. The positions of the auxiliary wire and main trolley wire are shown at *g* and *h*, respectively. Each catenary cable consists of two cables clipped together throughout their length, except for 3 feet on either side of the insulators, where they divide, and pass through grooves in each side of a malleable-iron ring cemented to the head of the insulator. The catenary cable is thus able to move slightly with regard to the insulators, and equalize the tension in the different spans.

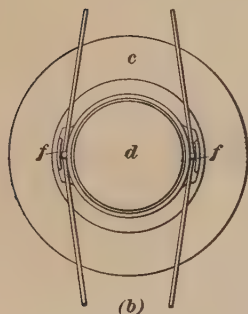
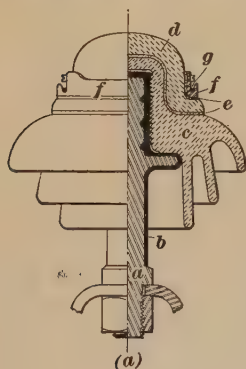


FIG. 60

133. Insulator for Siemens Catenary System.—The construction of the insulator for supporting the catenary wires is shown in Fig. 60, view (a) being an elevation, partly in section, and view (b) a plan. The insulator is fastened to a mild-steel bolt *a*, round which is moulded a hard-rubber sleeve *b*. Round this sleeve is placed the porcelain insulator proper, which is in two parts *c*, *d*, held together

by a layer of cement *e*. The main section *c* of the insulator is provided with three petticoats in order to make the leakage path from the cable to the pin *a* sufficiently long to reduce the leakage to a negligible amount. A malleable-iron ring *f*, cemented round the outside of the porcelain, contains grooves *g* constructed so that the strands of the catenary cable cannot be easily lifted out, but will allow motion along the cable.

FEEDER SYSTEMS ON ALTERNATING-CURRENT RAILWAYS

GENERAL CONSIDERATIONS

134. Sections and Feeders.—Feeder systems for alternating-current railways differ from those for direct-current railways, in that, on account of the much higher trolley voltages employed, the sections into which the working conductors are divided are much greater in length. The actual feeding arrangements adopted depend to a considerable extent on the drop of voltage allowable in the system. On lines which are not very long, extra feeders are not necessary, the working conductor being quite large enough to carry all the current required without excessive voltage drop when fed from one end. Where very long lines with heavy traffic are to be supplied, or where the generating station is at a considerable distance from the line, power is often transmitted at high voltage to transformer substations along the line. These substations contain only the static transformers and switchgear necessary to control the current, and require practically no attention, periodical visits being all that is necessary. When calculating the voltage drop in the overhead conductors, it should be remembered that, as the current is alternating, there is a drop of voltage due to reactance as well as that due to resistance.

135. Steel Rails as Conductors of Alternating Currents.—When an alternating current passes through an iron or steel conductor, the current is not distributed uniformly over the cross-section of the conductor, but is concentrated near the surface of the rail. This is known as the *skin effect*, and is due to the alternating magnetic field set up in the body of the conductor by the passage of the current, this field tending to force the current to the outer surface of the conductor. The equivalent resistance of the conductor is the same as if the current were uniformly distributed over a skin, or shell, on the outside of the conductor. The higher the frequency of the current, the more marked does this effect become.

136. Determination of Equivalent Resistance.—The equivalent resistance of the rail due to this effect varies, for a given frequency, with the magnetic qualities of the iron and the shape of the rail. The equivalent resistance of 1 mile of single rail may, however, be roughly calculated, for frequencies of 40, 25, and 15 cycles per second, by the following formulæ:

Let R_{40} = equivalent resistance of 1 mile of single rail at 40 ~, in ohms;

R_{25} = equivalent resistance of 1 mile of single rail at 25 ~, in ohms;

R_{15} = equivalent resistance of 1 mile of single rail at 15 ~, in ohms;

W_y = weight per yard of rail, in pounds

$$\text{Then,} \quad R_{40} = \frac{24.5}{W_y} \quad (1)$$

$$R_{25} = \frac{20.4}{W_y} \quad (2)$$

$$R_{15} = \frac{15.3}{W_y} \quad (3)$$

EXAMPLE.—Find: (a) the equivalent resistance of 2 miles of single track, consisting of two rails weighing 95 pounds per yard, when the frequency of the current flowing is 25 cycles per second; (b) the voltage drop in this track when the current flowing along it is 200 amperes.

SOLUTION.—(a) From formula 2, the equivalent resistance per mile of single rail is $\frac{20.4}{95}$ ohms; that of 2 mi. of single track, consisting of two rails in parallel, is therefore

$$\frac{20.4}{95} \times \frac{2}{2} = .215 \text{ ohm, nearly. Ans.}$$

(b) The voltage drop, given by multiplying the equivalent resistance by the current, is

$$.215 \times 200 = 43 \text{ volts. Ans.}$$

137. Alternating-Current Boosters.—In one respect the feeder system is not entirely settled by the transmission drop allowable. In direct-current practice, it has been laid down by the Board of Trade for tramways, and in some cases for railways, that the difference of potential between any two points of an uninsulated return must not exceed 7 volts. This regulation has been made

in order to protect masses of metal, such as water pipes, in the neighbourhood of the uninsulated return from damage due to electrolysis. At present, there is no Board of Trade regulation dealing with uninsulated return circuits for alternating-current railways; there is only the general obligation on the part of the railway company to pay compensation for any damage that can be proved to be due to any acts of theirs. In view of this, and of any requirement of the Board of Trade that may be laid down, it is general practice to limit the voltage drop in the uninsulated return, not necessarily to 7 volts, but to a reasonably low value. For this purpose, alternate-current boosters, or **sucking transformers**, have been applied in various ways to the feeder systems of alternating-current railways.

138. An alternating-current booster is simply a current transformer with a 1 to 1 ratio. The property of such a transformer is that, over its proper working range, the current in the primary

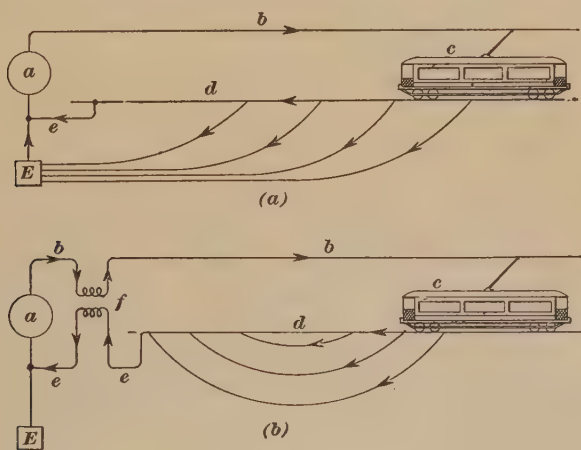


FIG. 61

must be equal to that in the secondary. The method of connection is shown in Fig. 61 (a) and (b). The alternating-current generators *a* supply current at high voltage over the line *b* to the train *c*. The current returns to the generators by way of the uninsulated track rails *d* and the return feeder *e*. Leakage may occur and a portion of the current may return by way of

the earth plate E , as shown in view (a). In the arrangement shown in view (b) the supply feeder b and the return feeder e are connected, respectively, to the primary and secondary windings of the current transformer f . Then, since the current in the two windings must be practically equal, all the return current must pass through the return feeder e . Thus, although there may be, and probably will be, a little leakage into and out of the

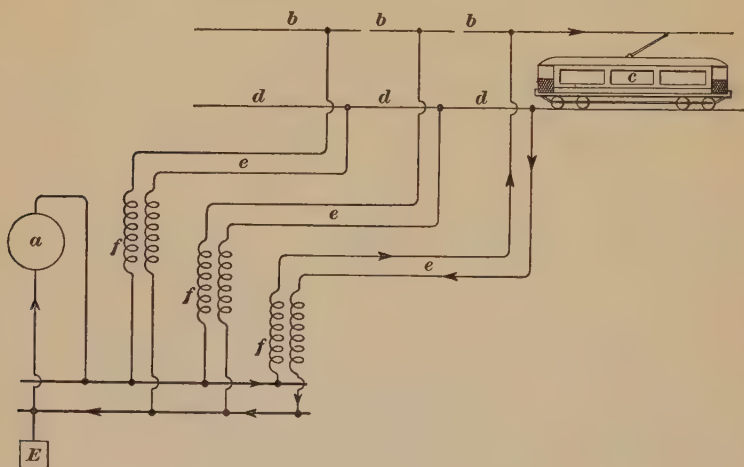


FIG. 62

uninsulated return, as indicated by the arrowheads, the greater part of the return current will pass along the rails, and there will be very little current in the earth. Where separate feeders are used, a sucking transformer should be connected in each, as shown in Fig. 62, which is lettered similarly to Fig. 61. There are several other methods of connecting the transformers to the feeders and return circuit, but the principle of action is the same in all.

ELECTRIC SIGNALLING ON RAILWAYS

SYSTEMS OF SIGNALLING

FORMS OF RAILWAY SIGNALS

EARLY TYPES

1. **Necessity for Signals.**—The introduction of the modern block-signal systems on large railways has greatly increased the efficiency and safety of train movements. By dividing the tracks into sections, called **blocks**, and installing certain safety devices, one train cannot approach another too closely without passing a warning signal, called a **block signal**.

On some of the early railways, where there was only one train running between two points, no signalling was required. With the development of the railways and the corresponding increase of trains and train movements on the same track, it became necessary to arrange for meeting points of the trains ; to install sidings for the passing of the trains ; to protect trains moving in the same direction by signals, in case the trains should come nearer to each other than a certain predetermined space ; and to protect trains moving in opposite directions by blocking.

2. **Ball-and-Mast Signal.**—In Great Britain, long before the telegraph was invented, signalling between stations was effected by means of a large ball that was raised or lowered on a high mast. One of these signalling devices was situated at each station and was operated by an attendant, whose duty was to

watch the signals at adjacent stations. Thus, for example, when a train left station No. 1, the ball would be raised to the top of the mast. When the train left station No. 2, the ball at that place would be raised to the highest position and the ball of station No. 1 would be lowered to half mast. When the train left station No. 3, the ball at that place would be raised to the highest position, the ball at station No. 2 would be lowered to half mast, and the ball at station No. 1 would be lowered to the ground. In this manner, the attendants at the stations were informed regarding the location of the trains. This system, however, could only be worked with stations very close together, and then only in day time and when the weather was clear.

SEMAPHORE SIGNALS

3. Home Signals.—In many modern signalling systems the

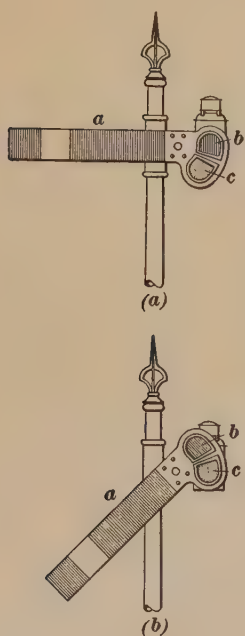


FIG. 1

the signal indicates that the block is clear and the approaching

driver of a train is informed of the condition of the block the train is approaching by means of movable signal arms, called **semaphores**. The arms are pivoted on posts and are arranged to move coloured lenses in front of a lantern, so that it is possible to tell the position of the semaphore at night by the colour of the light. A common form of semaphore is shown in Fig. 1. In view (a) the signal arm *a* is horizontal and the red lens *b* is brought in front of the lantern, so that at night a red light is displayed. In the position shown, the signal indicates that the block is occupied and the driver of the approaching train is to stop. In view (b) the arm *a* is at an angle of nearly 60° below the horizontal and the green or white lens *c* is brought in front of the lantern, so that at night a green or white light is displayed. In this position

train may proceed. A signal which shows the condition of the block immediately ahead is called a *home signal*.

4. **Distant Signals.**—It is often desirable to indicate at the entrance to one block the condition of the next succeeding block. In order to do this, special signals, called *distant signals*, are installed, and are arranged to indicate the position of the home signal one block in advance. The arm *a*, Fig. 2, of the distant signal is often provided with a V notch at the end, so that it may be distinguished from the home signal. If the distant signal is in the position shown in view (a), it indicates that the home signal, one block in advance, is at the danger position and the driver of the train must approach it with caution and be prepared to stop. If the signal is in the position shown in view (b), it indicates that the home signal one block in advance is at the proceed position. In this case the driver of the train knows that the two blocks ahead are clear and the train may proceed at full speed. Coloured lights are used to give the indications at night, as in the home signals.

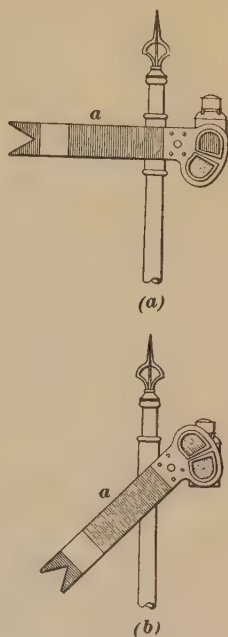


FIG. 2

5. **Arrangement of Home and Distant Signals.**—The home signal *a* of one block is often mounted on the same post as the distant signal *b* for the next block in advance, as shown in Fig. 3. The home signal is placed above the distant signal and indicates whether or not a train is in the block immediately ahead. If the semaphores are in the positions shown in view (a), the driver of the approaching train must stop before entering the block. If the semaphores are in the position shown in view (b), the driver is informed that the first block is clear, but the next home signal is at danger, and he must be prepared to stop the train at that signal if it still indicates danger when the train has reached the far end of the first block. When the semaphores are

in the position shown in view (c), the two blocks ahead are clear and the train may proceed at full speed.

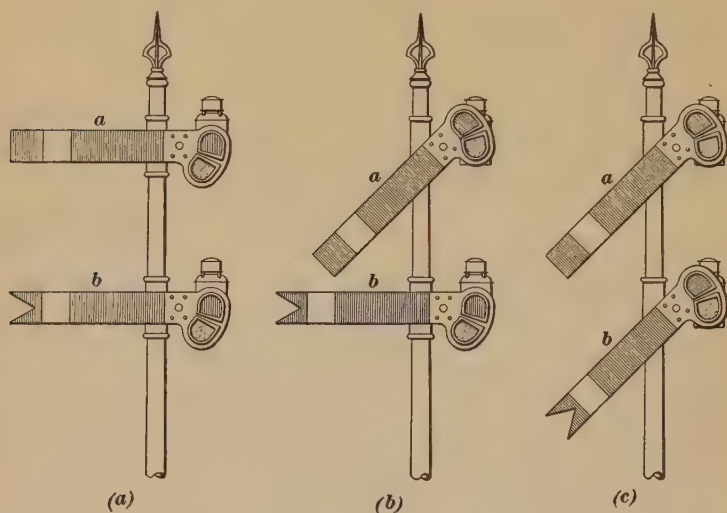


FIG. 3

6. **Banner-Type Signal.**—A type of signal sometimes used on lines at points where the running speed is not high is shown in

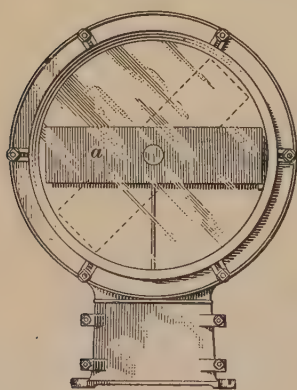


FIG. 4

Fig. 4. This signal is known as the **banner type**, and gives the same indication by day and night. It consists of a red banner arm *a* enclosed in a weatherproof case, the front of which is plain glass, and the back opalescent glass. The arm is pivoted at the centre, and in the danger position is horizontal, as shown. The clear position is indicated by the dotted lines. In day time, the light shining through the opalescent glass at the back shows up the arm very clearly, and at night a lamp is placed behind the signal,

so that the same indication is given as during the day. The signal is operated electrically by the action of an electromagnet.

TELEGRAPHIC BLOCK SYSTEMS

THREE-WIRE BLOCK TELEGRAPH INSTRUMENTS

7. **Types of Block Telegraph Instruments.**—Railway signalling which is accomplished by means of telegraphic block instruments, which the signalmen use to communicate with one another the conditions of blocks over which they have control, is known as the **telegraphic block system**. With this method of signalling the manipulation of the signals themselves is left to the intelligence of the signalmen, and the telegraphic block instruments are not interlocked in any way with the signals. This system of signalling is still in use on many railways. The block telegraph instruments in use may be broadly divided into two types: (a) Instruments in which the indicators are held in position by a constant current in the line, and which indicate *line clear* or *train on line*, according to the direction of flow of the current, and give the indication *line blocked* when current is switched off. This type usually requires three line wires. (b) Instruments which are made to indicate *line clear* and *train on line* by momentary currents in opposite directions, the indicators being held in position by the residual magnetism in the electromagnets after the current ceases to flow. These instruments usually require only one line wire.

8. **Construction of Simple Three-Wire Instrument.**—For three-wire working, separate wires are provided for the up and down lines and for the bell. In Fig. 5 is shown the appearance of the simplest type of instrument for three-wire working. The upper part *a* consists of a simple galvanometer, the needle of which can be made to deflect in either direction, according to the way current is passed through it. When deflected to the right, the needle indicates *line clear*; when deflected to the left, it indicates *train on line*; and when hanging vertical, *line blocked*. The lower part *b* of the instrument contains a simple commutator attached to the handle *c*, by means of which the direction of the current sent out by the instrument from the battery to the line

can be varied at will. When the handle *c* is in the central position, no current is sent out to the line. When moved to the

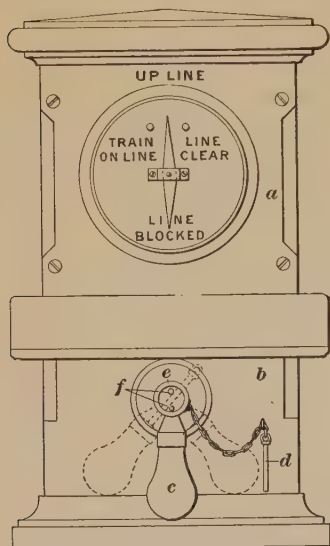


FIG. 5

left, current is sent to the line in such a direction that *line clear* is indicated on the distant instrument and on the dial above the handle. Similarly, if the handle is moved to the right, *train on line* is indicated. The positions of the handle when moved to one side or the other are shown dotted. When the handle has been moved to either position, it is held there by passing the peg *d* through a hole in the hollow spindle *e*, on which the handle is mounted; the peg passes between the pins *f*.

9. Operation of Three-Wire Instrument.

Four single block telegraph instruments are required in a signal station or box, one for the up line and one for the down line, connected to the next signal box on the right, and a similar pair connected to the next signal box on the left. The bells are separately wired up, and are not included in the instrument. Suppose that a train is to be sent from A to B. The signalman at A gives a definite pre-arranged number of strokes on the bell to signalman at B, who, if the block is clear, so that the train will meet no obstacles, turns the handle of the commutator of the telegraph instrument to the left, and pegs it there, thus causing the needle of the instrument at B and the needle of the corresponding instrument at A to indicate *line clear*. When the train leaves A, the signalman there signals the fact by means of the bell, and the signalman at B turns the commutator of the instrument to the right, and fixes it there, thus indicating *train on line* on both instruments. On the arrival of the train at B, the signalman there turns the handle so that both instruments indicate *line blocked*.

10. **Combined Instruments.**—For convenience in working, the instruments for the up and down lines and the bell are often combined into a single instrument. The arrangement of such an instrument is shown in Fig. 6. The dials *a* and *b* for the up and down lines, respectively, are placed in the upper part of the instrument; the dial *c* indicates the last signal given to the next box. The commutator is actuated by turning the disc *d* in one direction or the other, and the spindle of the plunger *e* for operating the switch of the signal bell circuit passes through the centre of the disc. Two instruments of this type are required in each signal box, one being connected to each adjacent box.

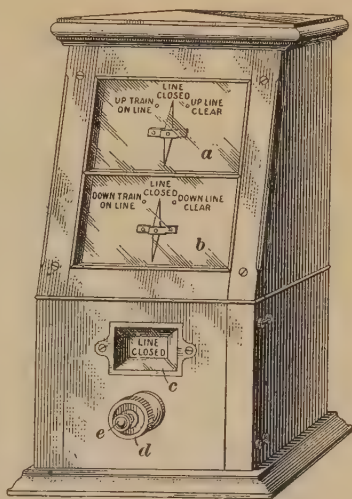


FIG. 6

ONE-WIRE BLOCK INSTRUMENTS

11. **Tyer One-Wire Block Instrument.**—The general appearance of a Tyer one-wire block instrument for giving three distinct indications is shown in Fig. 7. There are two pointers *a* and *b*, which refer to the up line and the down line, respectively. At the bottom of the instrument is a handle *c* for turning the commutator. A disc inside the instrument brings the words *line blocked*, *train on line*, or *line clear* into view in the window *d* as the commutator is turned to one of its three positions. The plunger *e* for ringing the bells projects from the centre of the commutator handle. The small plunger *f* operates a stop-lever, or detent, to stop the commutator in the desired position. The ringer is mounted in a separate case *g*, which also contains a relay. The instruments at adjacent signal boxes are connected and lettered so that the pointers for the down line operate in unison and also the pointers for the up line act together.

12. Arrangement of Fields and Armature.—In the Tyer one-wire block instrument there are two field poles a, a_1 , Fig. 8 (a),

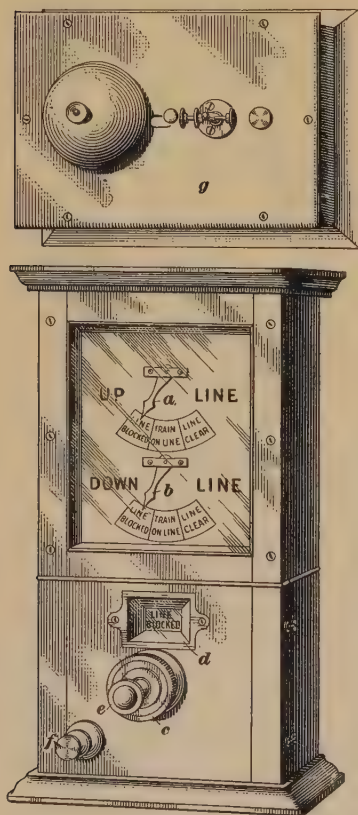


FIG. 7

and two permanently magnetized exciting poles b, b_1 for each of the armatures c and c_1 . The armature is a hollow cylinder of iron, split longitudinally and mounted on a brass boss. When the armature is in the position shown, the needle attached to the armature is inclined to the left, indicating *line blocked* on the face of the instrument. If poles a and b are of north polarity, and a_1 and b_1 of south polarity, the armature c will turn in a clockwise direction, so that the lines of force passing from a to b_1 and from b to a_1 will have a path of low reluctance through the iron. If the polarity of the main field poles a, a_1 is reversed, while the polarity of the exciting field poles remains unchanged, the armature c will turn in a counter-clockwise direction, so that the two iron segments

will carry the lines of force from b to a and from a_1 to b_1 .

The motion of the armature in a clockwise direction may be limited by the stop d , which is controlled by the unlocking magnet e

13. Arrangement of Commutator.—The commutator used in the Tyer block instrument is made up of three sectors f, g , and h , Fig. 8 (a), insulated from the main contact-piece i . On the sector h a contact pin projects some distance beyond the face of

the sector, so that when it is in the proper position, immediately over the earthing spring j , it will make contact with the spring if the plunger is depressed. The spring j makes contact with the commutator only for the one position. The three positions of the commutator for sending the signals *line clear*, *line blocked*, and *train on line*, respectively, are shown on the diagram.

14. Operation of Tyler Block Instrument.—If a train is to be sent from station A , Fig. 8 (a), to station B , Fig. 8 (b), the method of operating the block instruments is as follows: The signalman at station A will depress the plunger of the instrument at A , thus connecting the springs k , l , and m together, provided the commutator is in the position marked *line blocked*. The earthed spring j is also connected to spring n and thus to the negative pole of the battery o . Current will flow from the positive terminal of battery o to terminal 1 —winding of unlocking magnet p —spring m —commutator sector i —spring k —special terminal 2 of the battery o . The armature q of the unlocking magnet p is raised so that the armature c_1 can move its full distance in a clockwise direction. From the special terminal 2 of the battery o current also flows through springs k and l —line terminal 3 and line to terminal $3'$ of the instrument at B —spring l' —contact $4'$ —terminal $5'$ —coils a' , a'' of main field for armature c' —terminal $6'$ —terminal $7'$ of relay—relay windings r' —terminal $8'$ —earth terminal $9'$ —earth terminal 9 on instrument at A —spring j —commutator sector h —spring n —negative terminal of battery o . The armature of relay r' of instrument at B will be drawn only to the spring stop s' and current will flow from the positive terminal of the battery o' —terminal $1'$ —exciting coils b' , b'' for armatures c' and c'' —terminal $10'$ —terminal $11'$ —armature of relay r' —spring stop s' —unlocking coil e' —terminal $12'$ —terminal $13'$ —coils t' of ringer—terminal $14'$ —commutator spring n' —negative terminal of battery o' . A signal is thus given on the ringer at station B and the pointers remain at the normal line-blocked position.

15. If the line is clear, so that the train from station A , Fig. 8 (a), can be accepted, the signalman at B , Fig. 8 (b), will turn the commutator of the instrument to *line clear* and depress the plunger. This action causes the lower pointer of the instrument

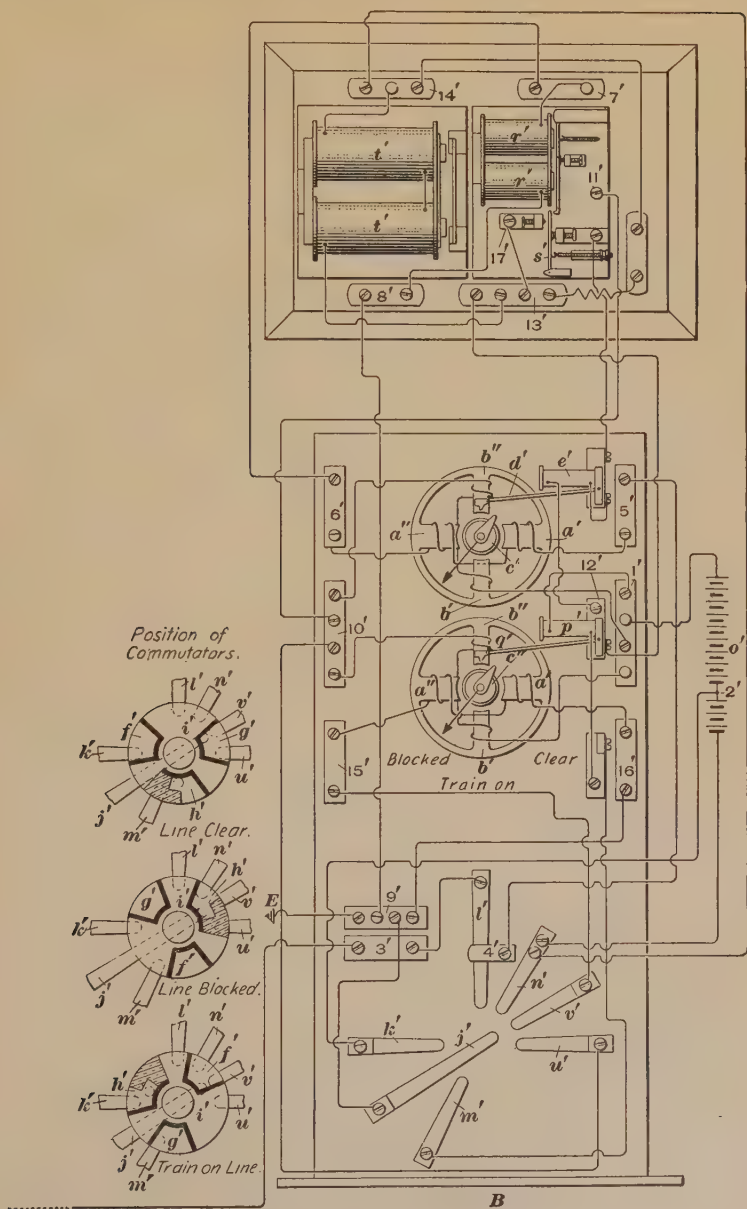


FIG. 8 (b)

at *B* and the upper pointer of the instrument at *A* to show *line clear*. Both these pointers refer to the up line, and therefore there is no chance of confusion. The path of the current is from the positive terminal of battery *o'*—terminal 1'—exciting fields *b'*, *b''* for armature *c''*—terminal 10'—spring *u'*—commutator sector *g'*—spring *v'*—terminal 15'—fields *a''*, *a'* for armature *c''*—terminal 16'—terminal 9'—earth *E* to instrument at *A*—terminal 9—terminal 8—coils of relay *r*—terminal 7—terminal 6—fields *a*₁, *a* for armature *c*—terminal 5—contact 4—spring *l*—terminal 3—line to instrument at *B*—terminal 3'—spring *l'*—segment *i'*—spring *n'*—negative terminal of battery *o'*. The armature of relay *r* at station *A* will be drawn against the stop 17, and a local circuit will thus be formed from the positive terminal of battery *o*—terminal 1—exciting fields for armatures *c* and *c*₁—terminal 10—terminal 11—armature of relay *r*—stop 17—terminal 13—coils *t* of ringer—terminal 14—spring *n*—negative terminal of battery *o*. Armatures *c* of instrument at *A* and *c''* of instrument at *B* will turn, so that the pointers indicate *line clear*. The signalman at station *A* will then set the outdoor starting signal at clear, and by means of the bell indicate to the signalman at *B* that the train is entering the section.

16. The signalman at station *B*, Fig. 8 (*b*), will reply to the train entering section signal by turning the commutator of the instrument to train on line and pressing the plunger. This action connects the negative terminal of the battery *o'* through spring *n'*—commutator sector *j'*—spring *v'*—terminal 15'—main fields *a''*, *a'* for armature *c''*—terminal 16'—terminal 9'—to the earth, and the positive terminal of battery *o'* through exciting coils *b'*, *b''* for armature *c''*—terminal 10'—spring *u'*—sector *i'*—spring *l'*—terminal 3'—to the line. The reversing of the battery connections in this way causes the armatures *c''* and *c* to turn in a clockwise direction as far as the stops *q'* and *d* will allow, and will cause the pointers to indicate train on line.

After the train has passed out of the section, the signalman at *B* will turn the commutator of the instrument to line blocked and depress the plunger. This action will restore the instruments to their normal condition.

LOCK-AND-BLOCK SYSTEMS

AUXILIARY APPARATUS FOR LOCK-AND-BLOCK SYSTEMS

17. Necessity for Interlocking.—The safe operation of a telegraphic block system depends on the signalmen implicitly obeying the indications of the block instruments, and using the utmost care in performing shunting and other operations. Accidents have frequently occurred through the failure of signalmen to work the signals in accordance with the indications given by the block instruments. In order to prevent mistakes of this kind, many interlocking systems have been developed, in which the signalman is compelled, by interlocking the outdoor signals with the block instruments, to work the signals in accordance with the indications of the block instruments. In the **lock-and-block system**, the signals and telegraphic instruments at both ends of a block are interlocked in such a way that it is impossible for a clear signal to be set, except by the simultaneous co-operation of the signalmen at both ends of the block. In this system, the signal is normally locked in the stop position, and communication between stations is maintained by telegraph, by telephone, or by code bells.

18. Use of Rail Contacts.—Rail contacts, or treadles, are used to complete the circuit of certain electromagnets, which lock the signals and prevent them from being lowered until the train has passed over the rail contacts, when the electromagnets unlock the signals. They are also used to put signals to danger after the passage of a train. It is essential that a rail contact shall be sure in action, and it must not be capable of being actuated by hand, or by being walked or jumped on, or by a moderate weight falling on it. In order to comply with these requirements, it is clear that the only satisfactory rail contact is one which is actuated by the deflection of the rail when a train passes over it.

19. Sykes Rail Contact.—There are numerous types of rail contacts in use, one of the best known being the Sykes rail contact, shown in Fig. 9, view (a) being a side view of the rail and treadle

attachments, view (b) a plan, and view (c) an end view. The angle-iron treadle *a* is carried by the cast-iron brackets *b* and *c*, which are firmly bolted to the rail *d*. Midway between the brackets *b* and *c* a third bracket *e* is attached to the rail; the end of the bracket bears on the short ends of two levers *f* and *g*, which are pivoted to the treadle *a* at the points *h* and *i*, respectively. The other ends of the levers *f* and *g* are situated immediately beneath the mercury cups *j* and *k*, which are pivoted between the treadle *a* and brackets *l* and *m* attached to the treadle. Each mercury cup is furnished with two contact wires, which are connected by the mercury when the mercury cups are tilted. The action of the device is as follows: When a train passes, the bracket *e* is depressed and forces down

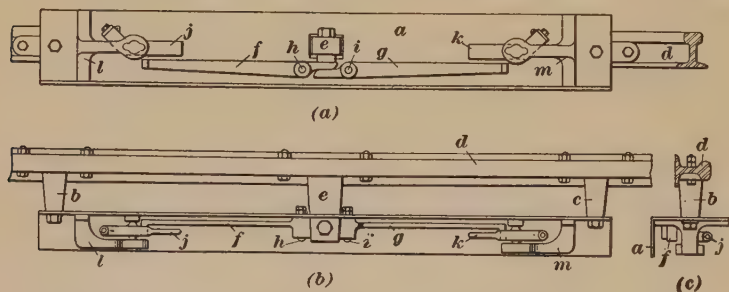


FIG. 9

the short arms of levers *f* and *g*, causing their long arms to rise and tilt up the mercury cups *j* and *k*, thus making contact between the contact wires dipping into the mercury cups. The two sets of contact wires are connected in parallel, thus reducing the risk of failure.

20. Siemens Rail Contact.—Another type of rail contact in which mercury is employed is the Siemens contact, shown in Fig. 10, view (a) being a side view of the complete apparatus, and view (b) an end section. The device is supported from the flange of the rail *a* by the small girders *b*, which are attached to the flange by bolted clips *c*. The main mercury container is situated immediately below the rail, and is divided into two portions by a thin flexible steel diaphragm *d*, the space under the diaphragm being filled with mercury. On the top of the

diaphragm is placed a cast-iron disc *e*, in contact with which is the cylindrical steel plunger *f*. This plunger passes through the cover *g* of the container and just touches the under side of the rail flange. Between the cover *g* and the under side of the rail flange, encircling the plunger *f*, is placed an india-rubber ring *h*, to prevent sand or dirt from interfering with the action of the plunger. When a train passes over the device, the downward movement of the rail *a* is transmitted by the plunger *f* and disc *e* to the diaphragm *d*, which also moves downwards, and forces

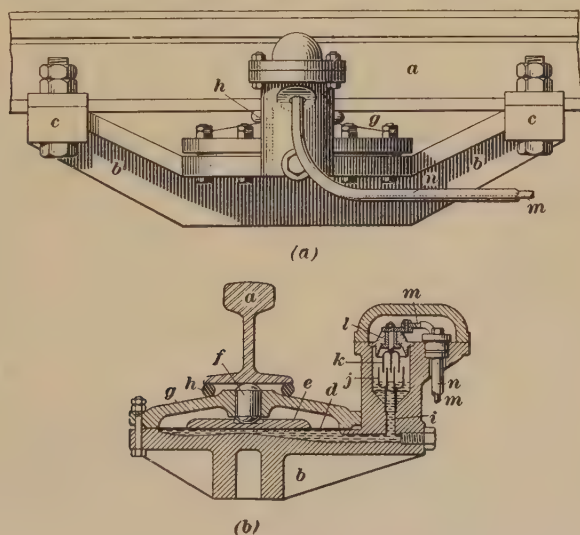


FIG. 10

some of the mercury beneath it up the pipe *i* and into the cup *j*, where it joins up the contacts of the fork *k*. The fork *k* is carried on a slate cap *l*, and is connected to a wire *m*, which passes out of the apparatus through the pipe *n*. The cup *j* is provided with openings which allow the mercury to run out when the pressure is removed from the rail.

21. Hollins Treadle.—A form of rail contact, known as the **Hollins treadle** and used on the Great Eastern Railway, is shown in Fig. 11, view (a) being a side elevation and view (b) an end elevation of the contacts. In this type of treadle the use of

mercury is avoided by the employment of a metal contact-piece making a rubbing contact with two springs. The lever *a* is pivoted at *b*, and is provided with a tail-piece *c*, which is let into a slot in the web of the rail *d*. Attached to the other end of the lever, but insulated from it by the insulation *e*, are two brackets *f*, *g*, which support a curved steel rod *h*. The bracket *i*, which carries the wedge *j*, is arranged to be a sliding fit on the curved rod *h*, so that if sufficient pressure is placed on the bracket *i* it will slide on the rod. When a train passes, the short arm of the lever *a* is depressed and the long arm rises, taking with it the bracket *i* and contact wedge *j*, thus causing the metallic portion *k* of the wedge to make contact with the springs *l*, *m*. Two steel stops *n* and *o* limit the movement of the bracket *i* to the required amount; should the movement of the lever be greater than is

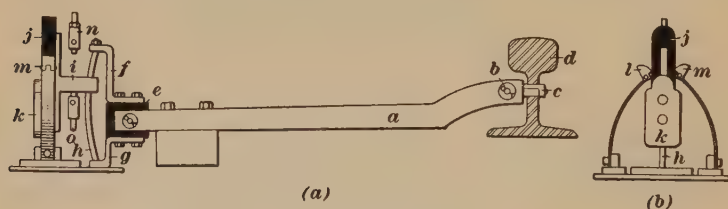


FIG. 11

required, the bracket *i* comes in contact with one of the stops and the rod *h* slides through the bracket *i*. The device is thus self-adjusting, and is very satisfactory, the number of failures in practice averaging less than 1 in 1,000,000 operations.

22. Fouling Bars.—On certain parts of a railway, as at terminal stations and sidings, a device known as a **fouling bar**, which is actuated by a train standing at the station, or in the siding, is required. In the case of a terminal station, this device must indicate that the particular line is occupied by a train, and so lock the signals that a signalman cannot admit another train on the same line. In the case of a siding, the device is used in conjunction with a rail contact, and prevents the signalman from admitting another train to the section until the first train is completely in the siding and clear of the main line.

23. The construction and action of a Sykes fouling bar are shown in Fig. 12, view (a) being an elevation and view (b) a plan. By the side of the rail *a* is placed an angle-iron bar *b* carried on the ends of levers *c* pivoted at *d*. The other ends of the levers *c*

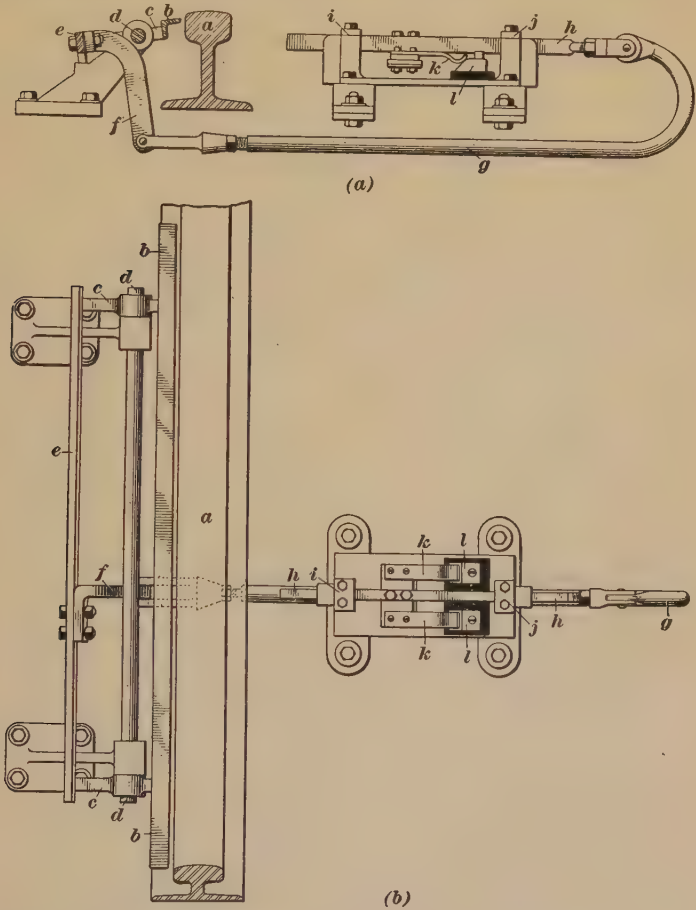


FIG. 12

are attached to the heavy bar *e*, which is connected by means of the arm *f* and the curved rod *g* to the bar *h*, which slides in the bearings *i* and *j*. To the under side of bar *h* are attached contact springs *k*, which normally make contact with the blocks *l*.

These blocks are mounted on insulating bases and form the terminals of the device. When a train is standing over the fouling bar *b* it is depressed by the flange of a wheel ; this raises the bar *e*, which, through the arm *f*, pulls on the rod *g* and causes the bar *h* to slide through the bearings *i*, *j*, thus breaking contact between the springs *k* and blocks *l*. The bar *b* must be made of greater length than the maximum distance between two axes on the train, in order to ensure that at least one wheel flange shall depress the bar.

24. Sykes Signal Reverser or Replacer.—It is desirable on a lock-and-block system that a train shall automatically place a signal that it passes to danger, independently of the signalman, as this ensures that the signal will always be at danger when the

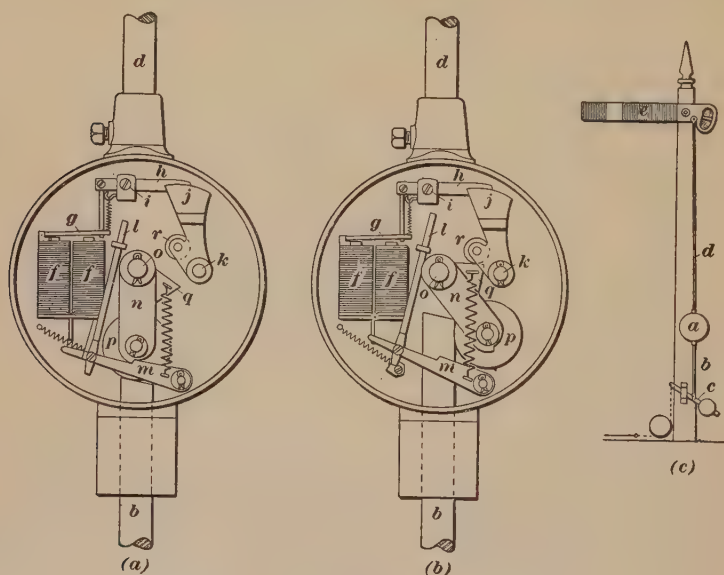


FIG. 13

block is occupied. A piece of apparatus for this purpose is called a **signal reverser**, or **signal replacer**. The details of construction of a Sykes signal reverser are shown in Fig. 13. It is placed as shown at *a* in view (c), and divides the vertical signal

rod into two parts, the lower of which, *b*, is joined to the balance-weight lever *c*, and the upper, *d*, to the signal arm *e*. The upper part *d* is fixed to the case of the reverser, and the lower *b* slides into the case, as shown in views (*a*) and (*b*), which illustrate in detail the mechanism of the reverser.

25. The mechanism of the Sykes signal replacer is shown in Fig. 13 (*a*) in the position it occupies when the signal is clear, or off, and the lever controlling the signal in the signal box is also at clear. When a train passes the signal, it operates a rail contact, which allows current to flow through the windings of the electromagnets *f*, the poles of which attract the armature *g*, thus raising the end *h* of a small lever pivoted at *i*, and allowing the hammer *j*, which is pivoted at *k*, to fall. At the end of its stroke, the hammer *j* strikes the upper end of rod *l*, depressing it and also the lever *m* to which it is attached. This releases the arm *n*, which is normally held vertical by a catch on lever *m*.

26. The arm *n*, Fig. 13 (*a*), is pivoted to the case of the reverser at *o*, and carries on its free end the steel roller *p*. Owing to the tendency of the signal arm to return to the danger position, when the signal is at clear, there is a constant pressure of the roller *p* on the top of the rod *b*, which is bevelled. The roller *p* and arm *n* thus continually tend to move to the right, but are prevented from doing so by the lever *m*. When the arm *n* is released in the manner just described, the roller and arm move to the right, the whole case of the reverser slides down over the rod *b*, and the signal goes to the danger position. As the rod *n* moves to the right, the projection *q* engages with the steel roller *r*, and raises the hammer *j* to the vertical position, where it is held by a catch on the lever *h*. The mechanism is then in the position shown in view (*b*). When the signaller puts the signal lever to the danger position, the rod *b* is withdrawn from the case of the reverser by the balance-weight lever *c*, view (*c*), and the arm *n* and roller *p* then return to the position shown in view (*a*). This device thus automatically puts the signal to danger after a train passes into the block and the signaller cannot place the signal at clear until he has first put the signal lever to the danger position.

27. **Tyer Signal Replacer.**—The working parts of a Tyer signal replacer are protected by a box *a*, Fig. 14, which is fastened to

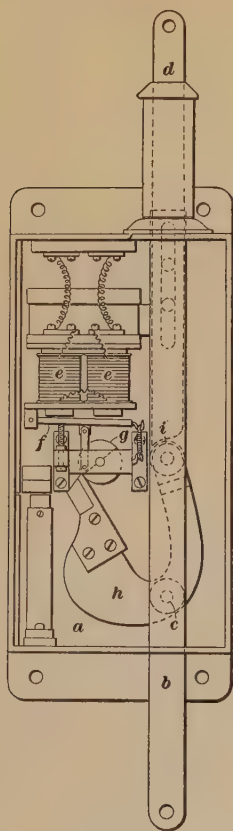


FIG. 14

the lower section *b* of the vertical signal rod by the pivot *c*. The upper part *d* of the signal rod is free to slide into and out of the replacer box *a*. The mechanism is shown in the position it would have if the signal were at clear. When a train passes into the block it actuates a track contact and thus causes current to flow through the coils *e* of the electromagnet. The magnet will attract the armature *f*, which will turn drum *g* so that the tip of the hook-shaped lever *h* can pass through a slot in the drum. The lever tends to move to the right about pivot *c*, because of the pressure of the sloping end of rod *d* on the roller *i* of the lever *h*. The rod *d* will slide past the roller and the signal will go to danger position. When the signalman places the signal lever at danger, the replacer box *a* slides down rod *d* and the weight of the hook lever *h* brings it to its original position, where it is held by the drum *g*.

28. **Light Indicator.**—It is customary on British railways, especially when the signalman cannot see the signal lights, to provide **light indicators** in the signal cabins.

These instruments show whether or not the signal lamp is lighted, and, in the event of the light going out or burning low, ring a bell to notify the signalman of the fact. The way in which this indication is effected is shown in Fig. 15. The signal lamp *a* contains two pillars, which support a copper rod *b* immediately above the flame *c* of the lamp. This rod *b* is so arranged that its expansion when heated by the lamp flame causes it to complete the circuit between the two supporting pillars in the lamp.

Current then flows from the battery *d* through the rod *b* and line wire *e* to the indicator *f*; it then passes through the coils of the relay *g*, and returns to the battery *d* by way of the earth plates *E*. The completion of the circuit causes the needle of indicator *f* to point to *in* and the relay *g* to attract its armature *h*. Should the light in the lamp go out or get too low, the circuit through the rod *b* would be broken, the indicator *f* would point

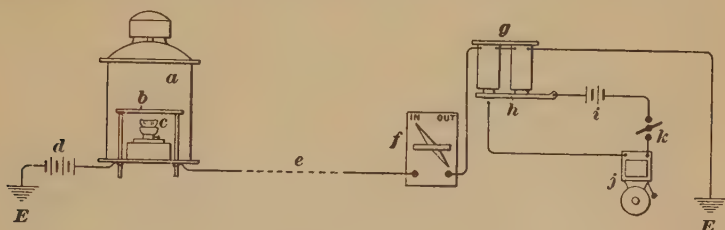


FIG. 15

to *out*, and the relay *g* would drop its armature *h*, thus completing a local circuit from the battery *i* through bell *j* and switch *k*. The bell continues to ring until the signalman turns it off by means of the switch *k*. Where several signals are situated close together, their light contacts can be connected in series to a common indicator, on which the failure of any one of them will be shown. This often effects a considerable saving in instruments and wiring.

29. Signal Repeater.

The position of signal arms which are not readily visible to the signalman should be repeated in the signal box. One method of doing this is shown in Fig. 16. The signal

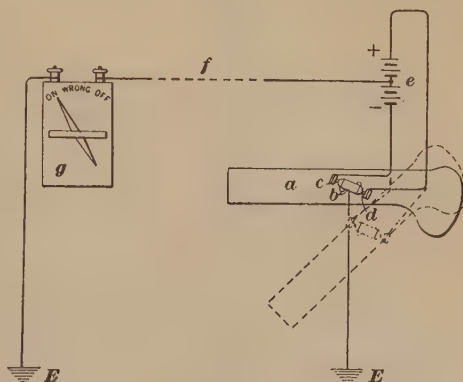


FIG. 16

arm *a* is provided with a tubular mercury commutator *b*, the main metal body of which is earthed. Contacts *c*, *d* project

into the tube at each end, but are insulated from the main body of the commutator. These contacts are connected to the terminals of the battery *e*, and a line wire *f* from the middle point of the battery runs to one terminal of the indicator *g*, the other terminal of which is earthed. When the signal arm is on, that is, in the danger position, current flows from the positive pole of the battery to contact *d*, and by way of the mercury in the tube to the main body of the commutator and to earth. It then passes through the indicator *g*, causing it to indicate *on*, and returns to the middle point of the battery on the line wire *f*. The upper half only of the battery is used to give this indication. When the signal arm is off, that is, in the clear position, the mercury in the commutator connects the negative pole of the battery to earth. The direction of the current through the indicator *g* is thus reversed, and the indi-

cation *off* is given, the lower half only of the battery being used. If the signal arm should fail to go fully to the on- or off-position, the mercury in the commutator does not make connection with either contact *c* or *d*, and the indicator is not energized in either direction; it then indicates *wrong*.

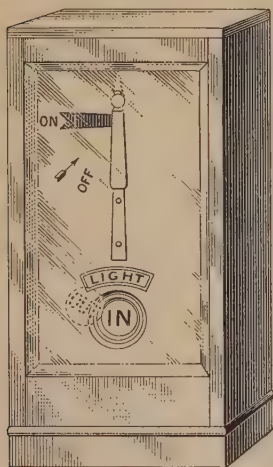


FIG. 17

30. The light indicator and signal repeater for one signal are often placed in one case in the signal box, thus avoiding confusion. The needle of the signal repeater is often replaced by a miniature semaphore arm, which can be coloured and either plain or slotted at the end, thus indicating which signal it is repeat-

ing. The appearance of such an instrument is shown in Fig. 17. The condition of the light is indicated by the appearance of discs, lettered *in* and *out*, opposite the circular aperture in the lower part of the instrument. If anything is wrong with the signal, the semaphore arm stops opposite the arrow, but otherwise indicates *on* or *off* in accordance with the position of the signal.

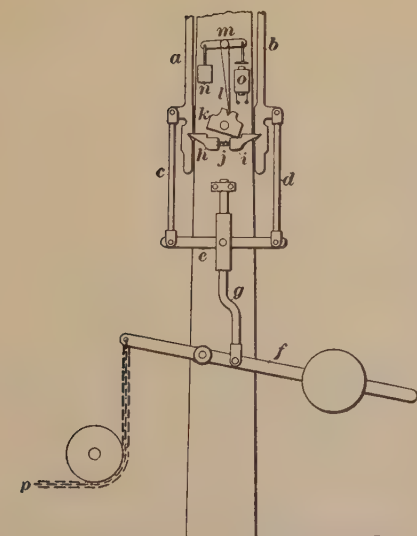
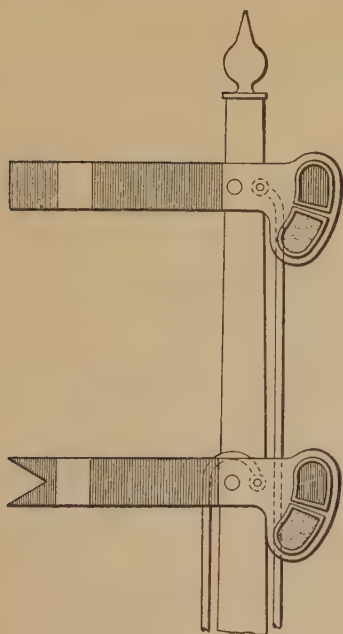


FIG. 18

31. Signal Selectors.

It is sometimes desirable to operate separately one of two or more signals situated on the same post by means of one lever. This is accomplished by the use of a signal selector, which selects which one of the signals shall be operated by the lever. The selector is usually connected up in such a way that the signal selected depends on the condition of the track ahead. There are several types of selectors in use on different systems. The arrangement of one selector suitable for two signals is shown in Fig. 18. The two vertical signal rods *a* and *b* are coupled by means of the bars *c*, *d* to the cross-bar *e*, which is connected to the balance-weight lever *f* by the rod *g*. The lower parts of the rods *a*, *b* are furnished with notches, into which fit lock-bars *h*, *i*. The lower surface of each notch, and the lower surface of each lock-bar are bevelled, so that when the rods *a*, *b* are pushed upwards the

lock-bars tend to slide out of the notches against the action of the spring *j*. This tendency is controlled by the rocker *k*, which is turned from one side to the other by the pointer *l*, pivoted at *m*, and actuated either by the weight *n* or the electro-magnet *o*.

32. Operation of Signal Selector.—The action of the mechanism of the signal selector shown in Fig. 18 is as follows: When one of the signals is to be put to the clear position, the lever in the signal box is pulled over, thus pulling on the chain *p* and raising the balance-weight lever *f* and the rod *g*. The upward motion of rod *g* is transmitted through the rods *e*, *c*, and *d* to the rods *a* and *b*, which both tend to rise. In the position shown, the electromagnet *o* is not energized, and the rocker *k* is tilted to the right by the action of the weight *n* and the pointer *l*. Lock-bar *i* is thus prevented from sliding out of the notch, and the rod *b* remains locked and cannot rise. Lock-bar *h*, however, slides out of the notch in rod *a*, which therefore rises, putting the lower signal to the clear position. Had the electromagnet *o* been energized, the rocker *k* would have been tilted to the left, and rod *a* would have been locked and rod *b* free. The upper signal would then have been lowered. The circuit of the electromagnet is controlled by the condition of the track ahead of the signals.

SYKES LOCK-AND-BLOCK SIGNALLING SYSTEM

33. Sykes Block Instrument.—One of the best-known and most-used lock-and-block signal systems in Great Britain is the Sykes system. The details of working and construction of instruments differ somewhat on different railways, but the main principle of operation is the same. The block instrument used is of the three-wire type, the up and down lines and bell having separate wires; the external appearance of the instrument is shown in Fig. 19. The instrument is provided at the top with a miniature semaphore *a* controlled from the station in advance. The dial *b* has two rectangular openings in its face, within the upper of which the words *free* or *locked* are displayed by the mechanism to show whether the signal connected with the

instrument is free to be operated or is locked. The lower opening either displays the words *train on* or shows a blank. The plunger *c* is used by the signalman when he wishes to accept a train from the preceding section, and the switch hook *d* is used to block the line during shunting operations. The block instrument is connected with the signal lever by the three rods *e*, *f*, and *g*. Of these, *e* is the signal-locking rod, *f* is the rod actuating the *train on* indication and locking the plunger when necessary, and *g* is the switching rod, which makes alterations in the electrical connections. When not in use, each instrument normally indicates *locked*, and has its miniature arm *a* at clear.



FIG. 19

34. Unlocking Magnet.—The electrical unlocking of the signals is effected by sending a current in a definite direction through the unlocking coils *a*, Fig. 20, which are fixed on soft-iron cores *b*, which form prolongations of the poles of the powerful permanent horseshoe magnet *c* in the block instrument.

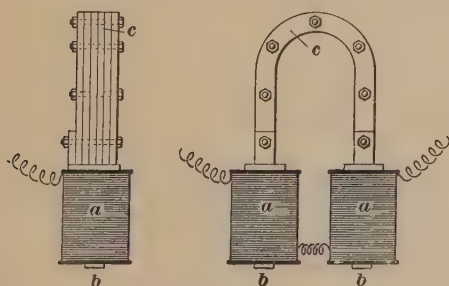


FIG. 20

When the signal is locked, the magnet *c* holds an armature to its pole pieces against the action of a spring. To unlock the signal, a current is sent through the locking coils *a* in such direction as to neutralize the

attraction of the permanent magnet, which then allows the

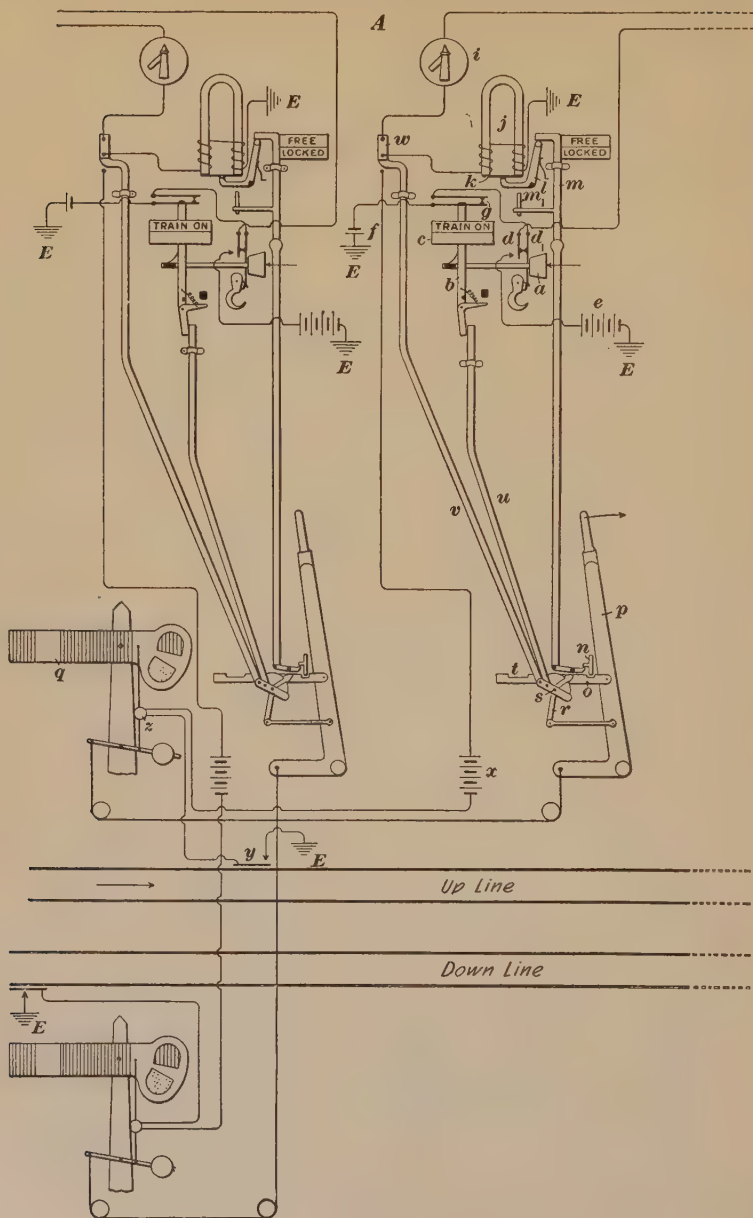


FIG. 21 (a)

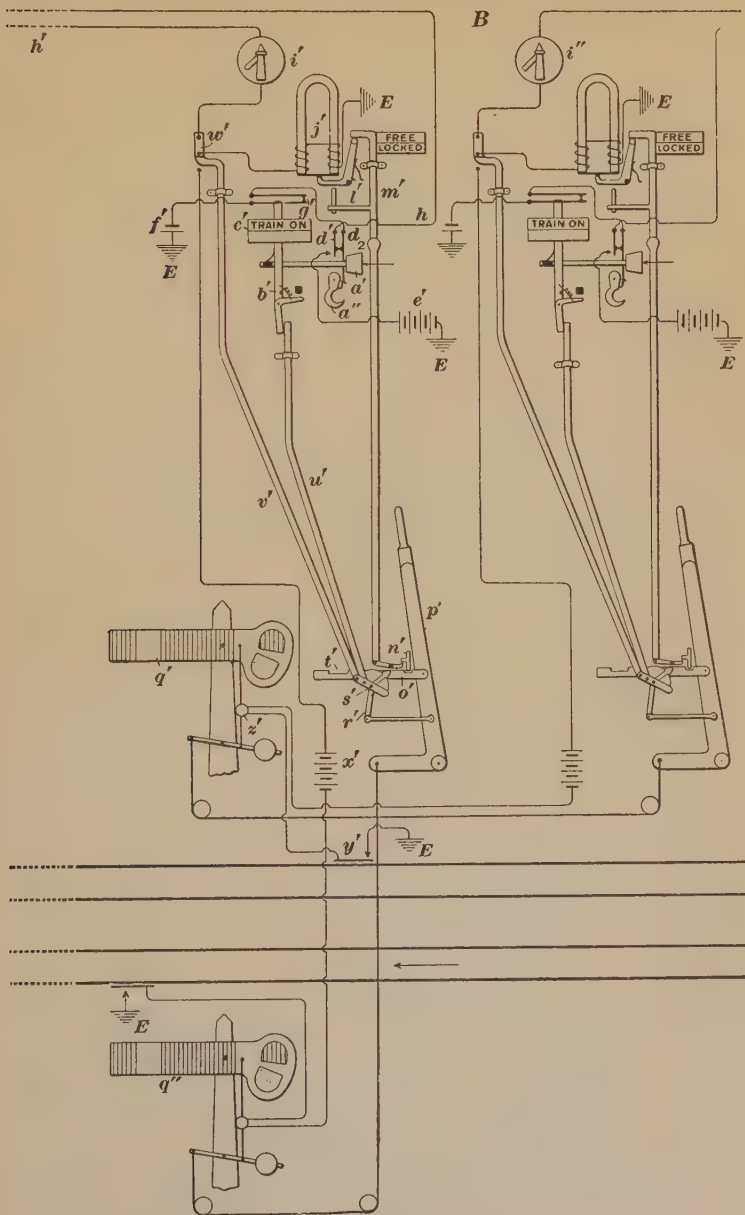


FIG. 21 (b)

armature to be pulled away by the spring, thus actuating the unlocking mechanism.

35. Operation of Sykes Signal System.—The operation of the Sykes lock-and-block signal system will be explained by reference to Fig. 21 (*a*) and (*b*), which shows the arrangement of the block instruments for a section of double track between *A* and *B*. The bell circuit, which is independent of the circuits of the block instruments, is omitted from the diagram in order to avoid complication.

If a train is at *A* and is to be sent on the *up line* to *B*, the signalman at *A* will first call up the signalman at *B* by means of the bell and give the signal asking if a train can be received at *B*. If the line is clear at *B*, the signalman will give the acceptance signal on the bell to the signalman at *A*, and will then push the plunger *a'* on the block instrument at *B* in the direction shown by the arrow. The plunger when pushed in is automatically locked, and the rod *b'* carrying the target *c'* is allowed to drop so that the words *train on* are displayed at the lower opening in the face of the instrument. The contact spring *d'* is joined by the movement of the plunger to the positive terminal of the battery *e'* and connection with the negative terminal of battery *f'* is broken at *g'*. The current from battery *e'* flows through the line wire *h* and causes the miniature semaphore *i* at signal box *A* to rise; current also flows through the coils of the permanent magnet *j*, thus demagnetizing the poles and releasing the armature *k*. The bell-crank lever *l*, which is attached to the armature, is moved to the left by a spring and the rod *m* is allowed to drop, thus displaying the word *free* in the upper opening of the instrument and raising the locking bolt *n* clear of the rod *o*.

36. The signalman at box *A*, Fig. 21 (*a*), can now move the lever *p* in the direction indicated by the arrow, thus lowering the starting signal *q*, which controls the up line between signal boxes *A* and *B*. On pulling the signal lever *p* to the clear position, the locking lever *r* is moved about its centre *s* and raises the rod *m* to the locked position, where it is held, because the armature *k* of the permanent magnet *j* is lifted into contact with the poles of the

magnet by a projection m_1 on rod m , thus moving the bell-crank lever l to the right and locking the rod m . The bolt n locks the signal lever p in the clear position by dropping into the slot t , which is made so wide that, when necessary for shunting, the lever p may be pushed back sufficiently far to set the signal q to danger without unlocking the block instrument for the acceptance of another train. The lever r , in moving in a counter-clockwise direction about the pivot s , draws rod u down, so that it will engage with a catch on rod b and raise the rod and the lower target c when the lever p is again placed in the position shown. The rod v is also drawn down when the signal lever p is moved to the clear position, and this causes the contact w to connect the terminal of battery x with the coils of the locking magnet j . When the train enters the block, it operates a rail contact y and connects the negative terminal of battery x to earth. Current flows from the battery x through the coils of the locking magnet j -earth E -rail contact y -signal reverser z -negative terminal of battery. This current causes the magnet j to release its armature k , which is forced downwards by the action of the spring on the bell-crank lever l , and the locking bolt n is raised by the falling of rod m . The word *free* is shown in the upper opening in the face of the instrument. The signal arm q moves to the danger position because of the action of the signal reverser z . The signalman at box A can now return the signal lever p to the danger position, where it is locked as shown in the diagram.

37. The signalman at box B , Fig. 21 (*b*), will call up the next signal box in advance and secure permission to admit the train to the block ahead of box B . When the plunger in the advance box is pressed, the miniature semaphore i'' at box B moves to a horizontal position, and the block instrument to which it is attached unlocks the lever controlling the starting signal q' , thus allowing the signalman at B to move the signal q' to the clear position. If at any time the signalman at B wishes to perform shunting operations which involve blocking or fouling the up line in any way, he should first turn the switch arm a'' , to the left, so that the insulated projection beyond the pivot will separate the springs d' and d_2 and interrupt the current from battery f'

to the line h , thus allowing the miniature semaphore i at box A , Fig. 21 (*a*), to go to the danger position. The hook at the end of the switch arm a'' fits over the end of the plunger a' , which cannot again be used until the switch arm a'' has been placed again in its normal position.

38. During the time that a train is running from A to B , Fig. 21 (*a*) and (*b*), on the up line a train may arrive at B to be sent on to A on the down line. The signalman at B , by means of the bell signal, asks if the train can be received at A , and if the down line is clear the signalman at A will depress plunger a of the block instrument, thus causing current to flow from battery e over the line h' to operate the miniature semaphore i' and cause the unlocking magnet j' to release the armature and unlock the lever p' , which controls the starting signal q'' . The train is sent on from A in the same manner as described for a train on the up line at box B . Any signal referring to the down line may be given regardless of the positions of the pointers which refer to the up line, the two parts of each instrument working independently.

39. Permissive Working of Sykes System.—At very busy points it is sometimes desirable to have a permissive system of signalling, so that more than one train may be allowed in a block at a time. In the Sykes lock-and-block signalling system two trains may be fully protected in one block by means of a permissive arrangement, consisting of an *advance starting signal* placed near the middle of the block between two signal boxes and controlled from the box ahead. The first train is allowed to enter the block in the usual way and the starting signal is put to danger behind it. The starting signal and the advance signal are interlocked so that the starting signal cannot be put to the clear position to admit the second train until the first train has passed a rail contact ahead of the advance signal and set it to danger. After the first train has passed out of the advance section of the block, the advance starting signal can be placed at clear to admit the second train. The operation of the permissive system is thus essentially the same as though an additional signal box were situated at the place where the advance starting signal is.

TYER LOCK-AND-BLOCK SIGNALLING SYSTEM

40. Construction of Tyer Lock-and-Block Instrument.—The lock-and-block instrument used with the Tyer lock-and-block signalling system is provided with two miniature semaphores, one for the up line and one for the down line. The lower semaphore in each instrument serves as an indicator of the signal sent to the next station. The commutator consists simply of a two-piece metal ring, the smaller segment *a*, Fig. 22 (*a*), forming an arc of about 60°. The two parts *a* and *b* are carefully insulated from each other, and are placed so that the spring 1 and spring 2 are joined to each other and spring 3 is connected to spring 4 when the commutator is in the position to display the notice *train out of section* on sector *D* or *train on line*, the latter notice being on a stationary vane behind sector *D*. If the sector *F* bearing the words *line clear* is in view, the commutator segment *a* will connect springs 1 and 3 and segment *b* will connect springs 2 and 4. The effect of this change is to reverse the connections to the battery *c*.

41. The sector *D*, Fig. 22 (*a*), bearing the words *train out of section* is loose on the commutator shaft, and the sector *F* indicating *line clear* is fixed to the shaft and turns with it. If the commutator handle is turned in a counter-clockwise direction the sector *F* comes against the sector *D* and moves it to the left, so that sector *F* is in view. After the line-clear signal has been given the handle may be turned in a clockwise direction, thus carrying sector *F* to the right. Sector *D* is held to the left by the lever *k* being caught by the hook on the armature of unlock-ing magnet *l*. When the words *train on line* are in view the *line-clear* indication cannot be given, as the lever *d* drops down so as to catch the edge of the sector *F*. The indication *train out of section* must therefore be given, so that sector *D* raises lever *d* each time before *line clear* can be obtained at the commutator. Signal replacers and track contacts are used in connection with the Tyer lock-and-block signal system. The signal levers are locked when in the danger position only, though it is possible to arrange the apparatus for double locking, if desired.

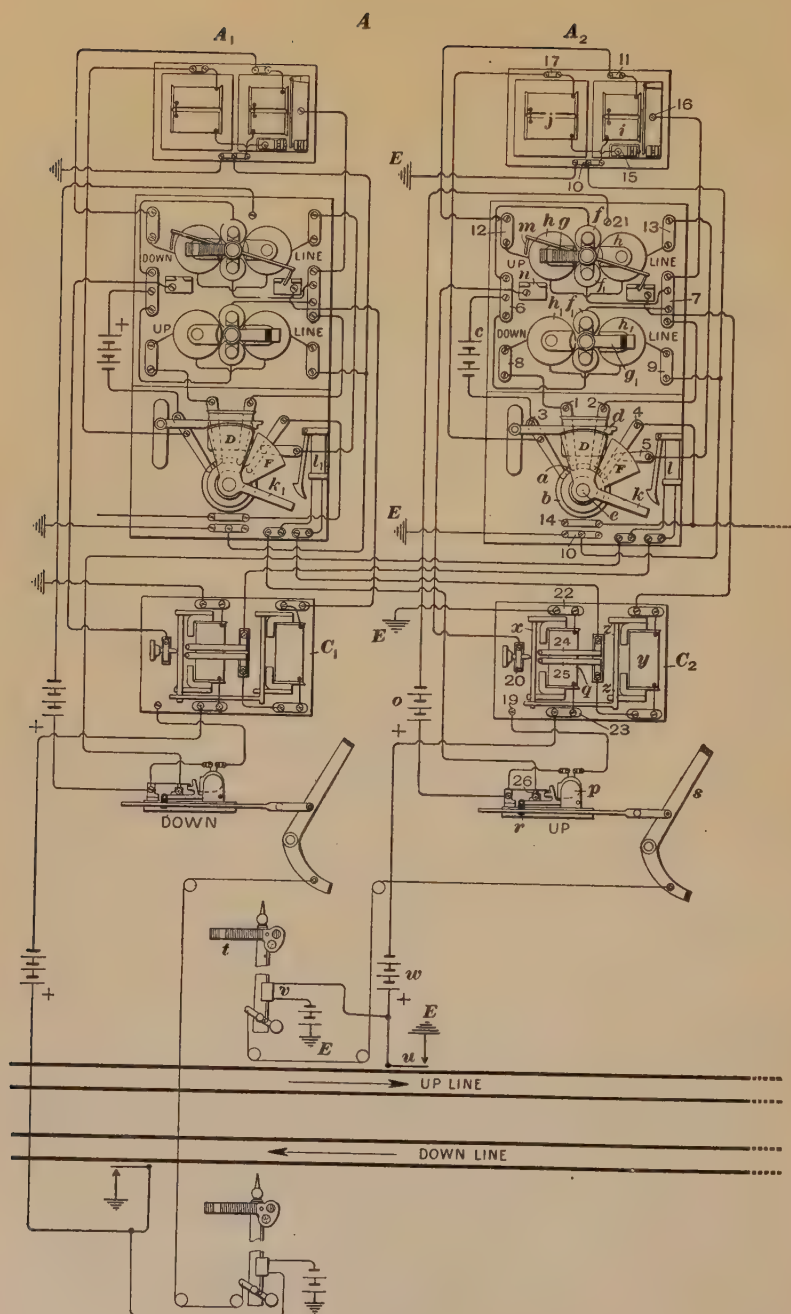


FIG. 22 (a)



42. **Operation of Tyler Lock-and-Block System.**—The connections of the instruments at adjacent signal boxes A, B for the Tyler lock-and-block signalling system are shown in Fig. 22 (a) and (b). The two instruments A_2 and B_1 will be in use when it is desired to send a train from A to B on the up line or from B to A on the down line. In order to explain the working of the apparatus, it will be assumed that a train is to be sent from A to B . The signalman at A will depress the plunger e of the instrument A_2 , thus causing the commutator segments a and b to connect the springs 1, 2 and 3, 4, respectively. At the same time, contact between spring 4 and stud 5 is broken. A momentary current flows from the positive terminal of battery c —terminal 6—exciting fields f, f_1 —terminal 7—spring 2—segment a —spring 1—terminal 8—fields h_1 —terminal 9—terminal 10—earth E to receiving instrument B_1 —terminals 10'—windings of relay i' —terminal 11'—terminal 12'—fields h_2 —terminal 13'—stud 5'—spring 4'—terminal 14'—line to instrument A_2 —spring 4—segment b —spring 3—negative terminal of battery c . The armature of relay i' , of instrument B_1 , is attracted against the stud 15', thus giving a circuit from the positive terminal of the battery c' —terminal 6'—exciting coils f_2, f_3 —terminal 7'—terminal 16'—armature of relay i' —stud 15'—windings j' of ringer—terminal 17'—spring 3'—negative terminal of battery c' . The semaphores g_1 of instrument A_2 and g_2 of instrument B_1 will remain up, as the current tends to hold the armatures in the original positions; the bell of instrument B_1 will ring.

43. The signalman at B , Fig. 22 (b), will, if the line is clear, turn the handle of the commutator of instrument B_1 to the left, thus bringing the notice *line clear* on sector F into view and raising the lever k' above the hook on the armature of the unlocking coil l' . When the plunger e' is depressed, the positive terminal of the battery c' will be connected to the line through springs 2' and 4' and commutator segment b' . The reversal of current in the line circuit will cause the semaphores g_3 of instrument B_1 and g of instrument A_2 to drop. The lever k' of the sector D is held up by the hook on the armature of the unlocking coil l' . The unlocking coil l' is not excited, as the circuit through it is open at the springs 24' and 25' of the lower relay C_4 .

44. When the upper semaphore g of instrument A_2 at station A , Fig. 22 (a), drops, the contact m is brought into the mercury cup n . A circuit is thus formed from the positive terminal of battery o —unlocking magnet p of the signal lever s —stud 19—on relay C_2 —armature x —contact stud 20—mercury cup n —contact m —terminal 21—negative terminal of battery o . The armature of the signal unlocking magnet p is attracted, thus raising the lock r so that the lever s can be moved and the semaphore t set to indicate a clear line. As soon as the signalman at A has set the starting semaphore t to clear, he signals on the bell to indicate at station B , Fig. 22 (b), that a train is entering the section. On receipt of this information the signalman at B will turn the commutator of instrument B_1 to the right, thus moving the sector F to one side, so that the words *train on line* are brought into view. The sector D is held to the left by the lever k' and the hook on the armature of magnet l' . When the signalman at B depresses the plunger e' to send the *train on line* signal to the signalman at A , the direction of current is such that the semaphores g_3 and g are raised to the danger position.

45. As soon as the train has entered the section at A , Fig. 22 (a), it passes over a rail contact u and causes the signal replacer v to set the starting signal t to danger. There is also a circuit formed from the positive terminal of battery w —rail contact u —earth E to terminal 22 of relay C_2 —winding q —terminal 23 and to negative terminal of battery w . The magnetism set up by the current in coil q will attract the armature x and thus join springs 24 and 25 of the relay. A circuit is thus completed from the positive terminal of battery o —contact 26 on locking magnet for up signal lever s —through the unlock magnet l_1 of instrument A_1 —spring 24 of relay C_2 —armature x —spring 25—magnet coil y —right-hand mercury cup—contact of semaphore g —terminal 21—negative terminal of battery o . The unlock magnet will attract its armature and the weight of the lever k_1 will cause the *train out of section* sector D to move into view before the window in the front of the instrument. Magnet y will attract armature z and this will release armature x , which will take up its original position and break contact with springs 24 and 25.

OPERATION OF SINGLE LINES

46. Original Method.—The safe working of single lines, over which trains must travel in both directions, is a much more difficult problem than the operation of double lines. In the early days of railway working, a pilotman was allotted to each section of single line. This pilotman accompanied all trains over the section, and if there were two trains waiting to proceed in the same direction, he dispatched the first and followed with the second, or with the last, if there were more than two. The pilotman usually issued tickets to the advance trains as authority to proceed without him. The place of the pilotman was afterwards taken by a wooden train staff. There was one train staff to each section, without which no train was allowed to enter a section. To provide for cases where more trains than one were waiting to enter a section in the same direction, tickets were provided, which were placed in a box which could be unlocked only by the train staff itself. The train staffs were eventually made of metal, and so constructed that they could be used to unlock the ticket box, but could not be removed until the lid of the ticket box was closed. Even with this method of working, there were errors and delays which made the method both unsafe and wasteful of time.

47. Use of Staff and Tablet Instruments.—In order to overcome the difficulties of the early train-staff systems, instruments were devised which issued train staffs or tablets under the control of lock-and-block systems of telegraphing. The instruments are so arranged that a staff or tablet cannot be withdrawn at one end of the section without the concurrence of the signalman at the other end of the section, and that when a staff or tablet is issued from end A of a section it is impossible to issue one from end B until the tablet issued at A is placed in the machine at B. The staff- or tablet-issuing machines can be electrically interlocked with the signals in such a way that the starting signal at one end of a section cannot be lowered until a staff or tablet has been obtained, thus making it impossible to show a clear signal if there is a train on the line.

POWER OPERATION OF POINTS AND SIGNALS

ELECTRIC AND ELECTRO-PNEUMATIC SYSTEMS

48. Advantage of Power Operation.—In early systems of signalling, and in many of the present ones, the work of moving points and signals is done by the signalman by means of levers connected through systems of rods, wires, and bell-cranks to the points or signals to be operated. Where the points or signals are situated at some distance from the signal cabin, the physical exertion required to operate them is often very great. The effect of this is to prevent the signalman from giving his whole attention to the train movements. The system of rods and wires necessary to work the points and signals of a large junction or terminus are often exceedingly complicated, and necessitate very large and unwieldy locking frames to contain all the levers. In order to obviate these difficulties, many railway companies are replacing the manually operated points and signals by those operated by power.

The points and signals may either be worked by compressed air or by small electric motors or solenoids. Whichever system is employed, the control is effected electrically by contacts in the signal box. As the levers for the points and signals merely operate electrical switches, they need only be large enough to give mechanical strength and to permit of being effectively locked; these levers can be moved with the utmost ease. The locking frames are greatly reduced in size and the interlocking very much simplified. For automatic signalling, power operation of the points and signals is, of course, essential.

49. Operation of Controlling Switches.—The arrangement of two of the point levers for an electrically operated system is shown in Fig. 23. The levers *a* and *b* are at a height of about 4 feet and 3 feet, respectively, above the floor of the cabin.

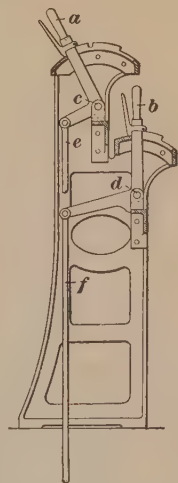


FIG. 23

They are pivoted in a light framework at *c* and *d*, and operate the switches for making the requisite connections to points and signals by means of the rods *e* and *f*. The type of switch used with the point levers shown in Fig. 23 is illustrated in Fig. 24.

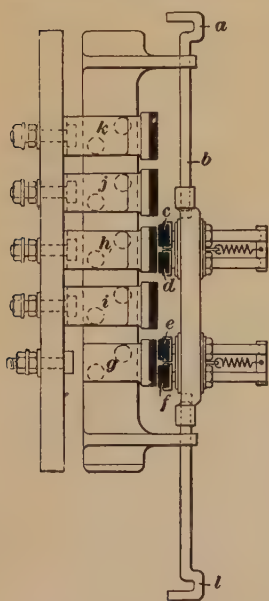


FIG. 24

An extension of the rod from the point lever is attached to the hook *a* on the rod *b*. The rod *b* carries two sets of carbon brushes, *c, d* and *e, f*, which press normally on the contact-blocks *g, h*.

50. Use of Check-Lock.—In a power system of signalling it is necessary to arrange matters so that a signalman shall not be able to complete the movement of a point lever, thus unlocking the signals in connection with the points, until the points themselves have moved to their proper position, and been bolted there. This is accomplished by means of a check-lock, which only allows a point lever to be moved half-way over at first. This allows the carbon brushes *c, d*, Fig. 24, to connect contact-blocks *j, k*, and brushes *e, f* to connect blocks *h, i*, thus sending power to operate the points. As soon as the points are bolted in place, a contact is made which releases the check-lock attached to the hook *l* and enables the movement of the point lever to be completed. The full movement of the lever unlocks the signals which have reference to the points.

51. Construction of Check-Lock.—The construction of the check-lock is shown in Fig. 25. The eye *a* on the bar *b* engages with a hook on the rod from a point lever, and the bar *b* is provided with two lugs *c* and *d*. Two pawls *e* and *f*, pivoted at *g* and *h*, respectively, are arranged so that one end of each is opposite to one of the electromagnets *i* and *j*. When the point lever is half-way over, lug *d* engages with pawl *f*, preventing further movement of the lever. When the points are finally bolted in

position, electromagnet *j* is energized and attracts pawl *f*, thus freeing lug *d* and bar *b* and allowing the movement of the lever to be completed. Similarly, when the points are put back, the pawl *e* engages with the lug *c* and prevents complete movement of the point lever until the electromagnet *i* is energized. In addition to the point check-lock, the point levers are interlocked with the block instruments in the same way as with the ordinary manual system.

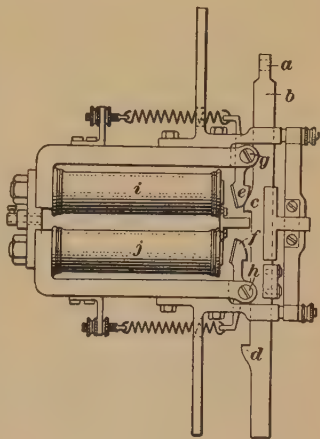


FIG. 25

52. Electrically Operated Point Movement.—The layout of an electrically operated point movement is shown in Fig. 26, view (a) being a plan, view (b) a side, and view (c) an end elevation. The enclosed motor *a* is mounted on the sole plate *b* bolted to the sleepers. The motor is connected by the universal joint *c*, which allows for the shafts being out of line, to the small friction clutch *d* and the worm *e* engaging with the worm-wheel *f*. Attached to the worm-wheel is a crankpin *g*, which moves inside the hollow cam-lever *h*, pivoted to the base at *i*. The end of the cam-lever is connected to the rod *j*, which operates the points through the rod *k*. The pin *g* on the worm-wheel *f* has also attached to it the rod *l*, which, through crank *m* and rod *n*, rotates the spindle *o* and raises the locking bar *p* by means of the rod *q*. This bar prevents the movement of the points during the passage of a train, since, in order to reverse the points, the bar *p* must be raised above the level of the rails.

53. The movement of the bar *p*, Fig. 26, is communicated to a second spindle *r* by the rod *s* and produces a thrust on the rod *t*, which thrust is transmitted to the sway beam *u* pivoted to the end of the rod. The sway beam carries at its ends two plungers or bolts *v, w*; when the points are home in one or the other of their two positions, holes in the stretcher bar *x*, which

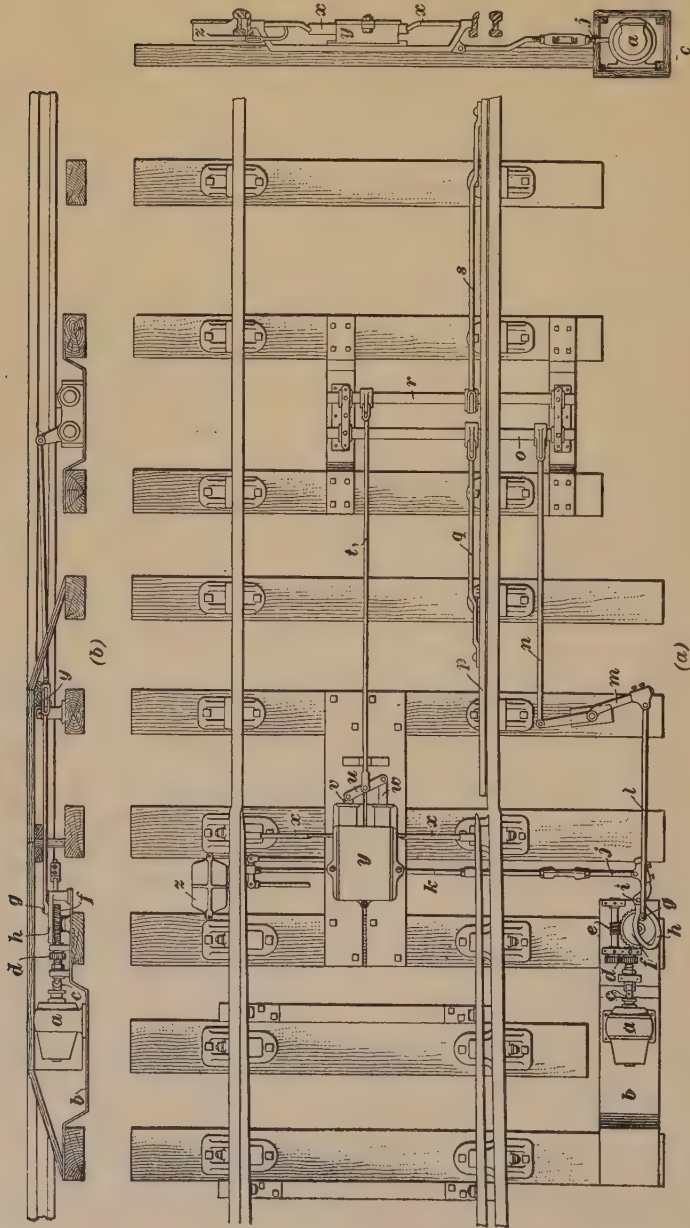


FIG 23

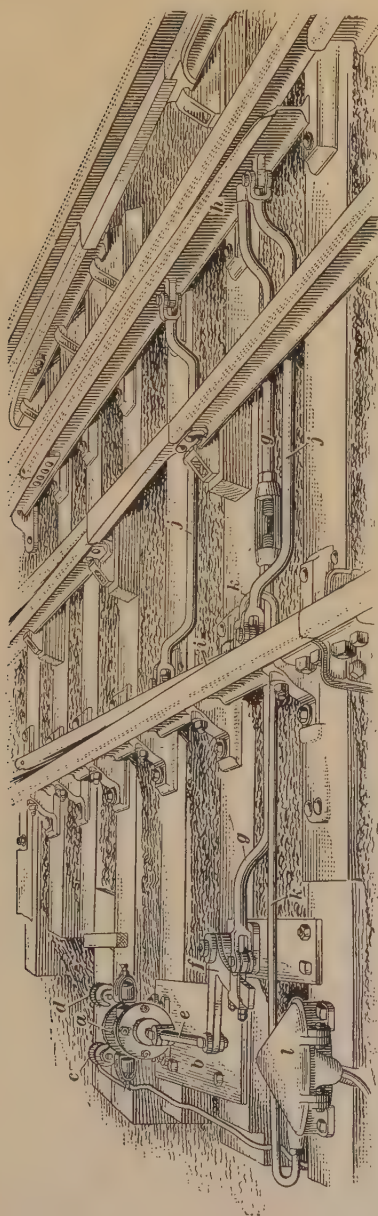


FIG. 27

connects the tongues of the points, come opposite to either plunger *v* or plunger *w*. Thus, in one position, plunger *v* passes through a hole in bar *x* and locks the points, and in the other position, plunger *w* passes through a hole in the bar and locks the points. Situated in the box *y* are contact springs actuated by the movement of the points, which break the motor circuit and reverse the connections to the motor armature when the movement is completed. The box *z* contains contacts connected with the signals in such a way as to prevent their operation unless the points are correctly set. The time taken to reverse the points is between $1\frac{1}{2}$ and 2 seconds, and the power required is about 6 amperes at 110 volts.

54. Electro-Pneumatic Point Movement.—In the electro-pneumatic system of operating points and signals, a main, carrying air at a pressure of 65 to 70 pounds per square inch,

is carried the whole length of the track to be signalled. Air from this main is admitted to one side or the other of a piston working in an air cylinder. The piston is thus forced in one or the other direction and actuates the points through a system of levers. The admission of air to the cylinders is governed by pin valves, which are controlled by electromagnets. A trailing point layout, where trains converge from two branches on to a single line, is shown in Fig. 27. The main air cylinder *a* is mounted on an iron base plate *b* secured to the sleepers. The electrically operated pin valves for controlling the admission and release of air are placed in the cases *c* and *d*. The motion of the piston is communicated through the rod *e*, crank *f*, and rod *g* to the point tongue *h*. The second point tongue *i* is operated from the first by the rods *j*. Attached to the second point tongue *i* is a rod *k*, which passes into the box *l* and actuates

the switches for releasing the various locks on signals, point levers, etc., and for indicating that the points have properly closed.

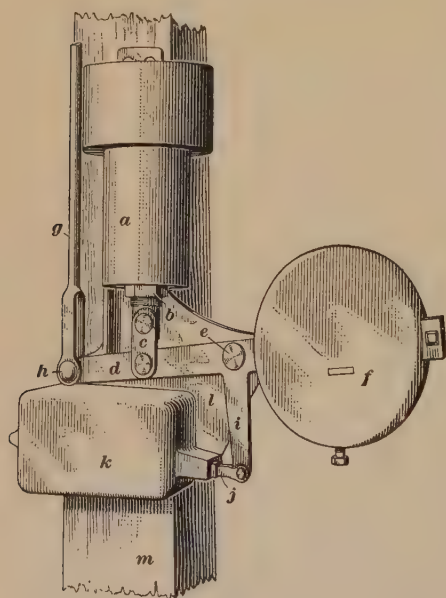


FIG. 28

is connected by the link *c* to the lever *d*, which is pivoted at *e* and provided with a counterweight *f*. The signal rod *g* is

55. Electrically Operated Signals.—Signals may be operated electrically by either motors or solenoids, and both methods are quite satisfactory. The way in which a signal is operated by means of a solenoid is shown in Fig. 28. The winding of the solenoid is contained in a cast-iron case *a*, and the plunger *b*

attached to the lever *d* at a point *h* beyond the link *c*. The signal arm is balanced so that it returns to danger when the solenoid is not energized. The arm *i* of the lever *d* actuates the rod *j*, which passes into the switchbox *k*. The solenoid requires a current of about 15 amperes at a pressure of 100 volts for a fraction of a second to pull the signal arm to the off-position, but to hold the arm at off only about 2 amperes is required. On this account, as soon as the signal is off, a resistance is switched into circuit with the solenoid winding by a carbon contact switch placed in the box *k*, and actuated by the rod *j*. The whole movement is mounted on a cast-iron base *l* and attached to the signal post *m*.

56. Electro-Pneumatic Signal Movement.—A sectional view of the air cylinder, control valve, and magnet of an electro-pneumatic signal movement is shown in Fig. 29. The compressed air from the main enters at *a* and is controlled by the valve *b*, carried on the end of the rod *c*, which is attached to the armature *d* of the electromagnet *e*. The valve *b* has two seatings. When the signal is in the normal *on- or danger* position, the electromagnet *e* is not energized, and the valve *b* is held up against the lower seating by a spiral spring, the upper part of the valve being open. This shuts off the compressed air and connects the upper part of the air cylinder *f* to the exhaust port *g* through the passage *h* and upper part of valve *b*. When the signalman pulls over the control lever the electromagnet *e* is energized and attracts its armature *d*, thus forcing the valve *b* down away from its lower seating and closing the upper seating. The compressed air then passes through the lower part of valve *b* and passage *h* to the upper part of cylinder *f*, forcing down the piston *i* and piston rod *j*, which is connected to the

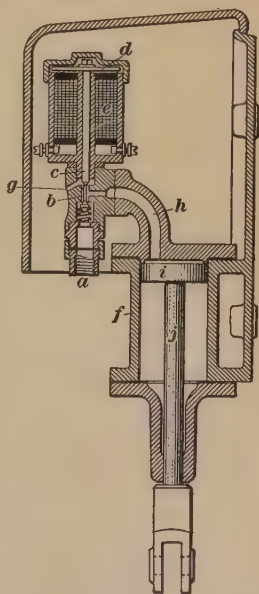


FIG. 29

signal rod through a lever. The signal is thus forced to the off- or clear position. When the magnet is again de-energized, the compressed air is again cut off at the lower part of valve *b*, the upper part of cylinder *c* is connected to the exhaust port *g*, and the signal returns to the on-position by gravity.

AUTOMATIC SIGNALLING SYSTEMS

ARRANGEMENT OF BLOCKS AND AUTOMATIC SIGNALS

57. **Necessity for Automatic Signalling.**—As traffic on the railways increased with but slight increase of track length, it became necessary to run the trains closer together, for which purpose the length of the block sections had to be reduced. In many cases the cost of providing a signal cabin for each block would be prohibitive; this and other reasons led to the invention of systems which would work automatically and dispense with the services of signalmen, such systems being known as **automatic block-signal systems**.

The operation of the signals of the **automatic block-signal system** is entirely controlled by the trains using the track to which the system is applied. A proceed signal is displayed to an approaching train, at the entrance to a block, provided that no other train is in the block and that it contains no open points or broken rail. The signal moves to the stop position as soon as the first pair of wheels of a train passes the entrance of the block, and the signal remains at this position until the last pair of wheels of the train has passed out of the block at the distant end.

Automatic signals are so arranged that they are held normally at clear. This is the case because the duty of an automatic signal is to indicate whether the section ahead of it is occupied or not. It should thus only stand at danger when there is a train in the section ahead. In case of any failure of the apparatus, however, automatic signals are arranged to return to the danger position by gravity.

58. Length of Block Sections.—In order to secure the safe maximum capacity for train movements over a given piece of track, it is necessary to know the maximum distance required for stopping the fastest train on the road. Air-brake tests will determine this distance, and for maximum train capacity, the length of the block should be equal to this value, but should not be less.

Since it is more difficult to stop on a descending grade and less difficult to stop on an ascending grade, the blocks should be lengthened on descending grades and shortened on ascending grades. As large terminals are approached, the blocks should be shortened on account of the limited speed of trains and the congestion of traffic at such places.

59. General Requirements of Signal Control.—Having fixed the positions, the control of the signals should be such as not only to warn the driver of the train when he reaches a block that is occupied, but also to warn him in time to permit him to stop the train before reaching the entrance of the occupied block. With this arrangement and control of signals, it would be possible to start two trains from one end of the line, space them two blocks apart, run them the length of the line at the same speed, and have them still two blocks apart when the first train reached the end of the line. The second train would receive clear signals all the way; or, if the first train should stop at any point, the second would receive due warning and have plenty of space in which to stop before reaching the block occupied by the first train.

60. Arrangement of Blocks.—In Fig. 30 is shown an arrangement of an automatic block system using semaphore home and

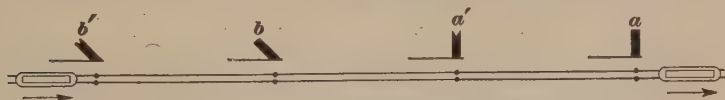


FIG. 30

distant signals mounted on separate posts. The ends of the home-signal arms are square, while the ends of the distant-signal arms are notched. The home signal *a* is shown in the

stop position, with a train just past it in the block. The distant signal for a is shown at a' . This signal is in the caution position, indicating to an approaching train, *expect to find the next home signal in the stop position*. Home signal b and distant signal b' are in the proceed position, since the train has just moved out of the block $a b$. Under this arrangement trains can be run at full speed, provided they are spaced a distance equal to one block, $a b$, plus the distance, $b b'$, between a home signal and its distant signal.

61. The indications and meanings of the signals shown in Fig. 31 are identical with those described in the preceding article. This arrangement is developed by reducing the length of blocks $a b$, $b c$, etc., until the home and distant signals a' and b , b' and c , etc., are so close together that it is best to mount them on the



FIG. 31

same post. Distant signal b' has just gone to clear, since the train has passed out of block $a b$. With this arrangement, trains running at full speed would be spaced two blocks apart, although the actual distance might be the same or shorter than that shown in Fig. 30.

62. **Overlap.**—In cases where an exceedingly frequent service of trains is maintained, as on underground electric railways, and the blocks are correspondingly short, distant signals are dispensed with, and the entrance of a train to each block is controlled by a starting signal. Each signal is governed by the condition of the section immediately in advance of it, and this section commences a certain distance in advance of the signal and extends to a similar distance beyond the next stop-signal. The distance by which the section extends beyond the signal is known as the **overlap**. The purpose of the overlap is to guard against a collision which might be caused by the driver passing a signal at danger, by allowing an additional space in which to bring the train to a stop before it enters the next section.

63. Automatic Train Stop.—As an additional safeguard against trains running past stop-signals, an **automatic train stop** is often used. This device is illustrated in Fig. 32, and consists of an arm *a*, standing beside the track rail *b*, outside the track. This arm is mounted on the spindle *c*, which is connected by the crank *d* and rod *e* with an air cylinder *f*. The admission of air to this cylinder is controlled by an electrically operated pin valve contained in the case *g*. When the adjacent signal is in

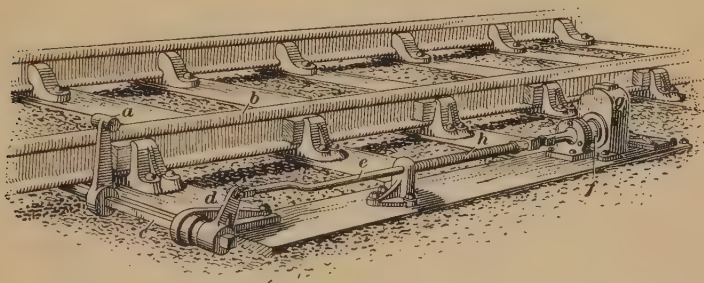


FIG. 32

the stop position, the spring *h* on the rod *e* forces the rod to the right, and the stop is raised. When the signal is lowered, air is admitted to the cylinder *f*, which forces rod *e* to the left and lowers the arm *a*. If a train passes over the arm *a* when it is raised, as shown in the illustration, the arm strikes the handle of a special valve which applies the air brakes and stops the train.

TRACK CIRCUITS

64. Principle of Operation.—It is clear that if the track rails themselves are used as the signal circuit, by connecting a battery across them at one end of a section, and a relay at the other, the relay will be energized as long as there is no train in the section, and will complete the circuit holding the signal in the clear position. When a train enters the section, the track rails will be short-circuited through the wheels and axles of the train, and but little current will flow through the relay, which will therefore drop its armature, and allow the signal at the entrance

to the block to return to danger. The track-circuit principle

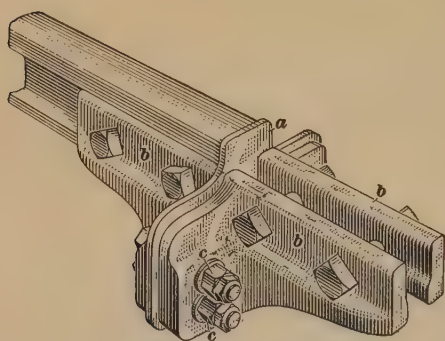


FIG. 33

is used not only in connection with automatic signals, but also for locking purposes where the signals are controlled by a signalman. It is often used to replace fouling bars.

65. Insulated Rail Joints.—The installation of a section of track circuit necessitates the

replacement of the iron fish-plate joints at each end of the section with an insulated joint, and the bonding together of the intermediate rails by running bonds of wire round each joint to reduce the resistance. A type of insulated joint for ordinary rails is shown in Fig. 33, one rail being removed in order to show the plate of insulating material *a*, which is clamped between the special fish-plates *b*. The clamping bolts *c* are insulated from the fish-plates by means of fibre washers and bushes.

66. Arrangement of Track Circuit for Steam Railways.—On steam railways, where both rails can be used for carrying current

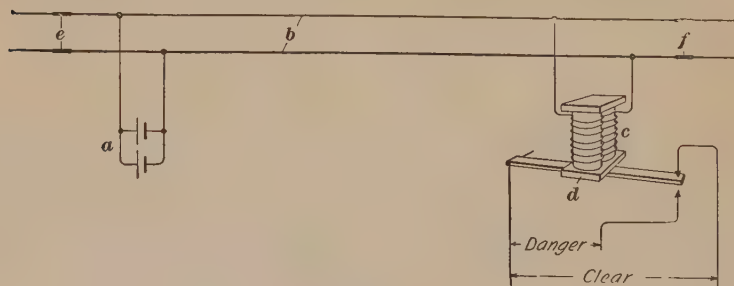


FIG. 34

for signal work, the track circuit takes the form shown in Fig. 34, in which the batteries *a* are connected across the rails *b* at one end of the insulated track section *e*, *f*, and the relay *c* is connected

across the rails at the other end. The relay has a pivoted armature d that carries contacts for controlling the signal, or auxiliary, circuits. The armature falls away from the magnet cores by gravity and requires that the magnets be energized in order to raise it. The track circuit is a closed circuit, and the relay is normally energized. The breaking of any wire in this circuit or the short-circuiting of the relay, caused by crossed wires or a train on the track circuit, in which event the wheels and axles cause the two rails to be connected together, will cause the relay armature to fall away from the cores, and break the circuit which supplies current to the apparatus holding the signal in the clear position.

WESTINGHOUSE TRACK-CIRCUIT SIGNALLING SYSTEM

67. Arrangement of Conductors and Track Sections.—When applying track circuits to an electric railway, great care has to be taken that the relays employed are not operated by leakage currents from the main conductors carrying the operating current for the trains. For this reason it is not possible to use the simple system shown in Fig. 34 for signalling on electric railways. A very successful system of track-circuit automatic signalling, which is unaffected by leakage currents, has been installed by the Westinghouse Company on several of the underground electric railways of London. In Fig. 35 is given a diagram of the connections of the system as installed on the Metropolitan District Railway. On this railway the track rails are not used as the return circuit for the current supplied to the trains, but the signalling system may be used where one of the track rails is made to carry the return current from the car motors. One track rail a is bonded up to form a continuous conductor, and this rail is connected to the positive pole of the direct-current generator c , which supplies current at a pressure of about 60 volts. The second track rail is divided up by insulated rail joints into sections b, b_1, b_2, b_3 , etc. An insulated signal main d is connected to the negative pole of the generator c and runs the whole length of the line. Each of the blocks of the sectionalized track rail is connected to the negative signal main through a resistance e, f, g , respectively, as shown.

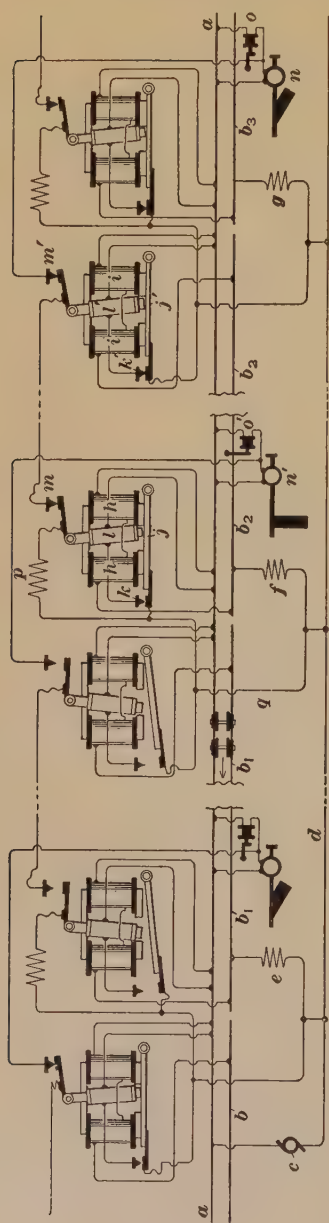


FIG. 35

68. Action of Relays.—In the Westinghouse track-signal system two relays are employed for each section, one being connected across the track rails at each end of a section. It is necessary for the contacts of both these relays to be closed at the same time before the signal can go to the clear position. The two relays for section b_2 , Fig. 35, have their main windings h, h and i, i , respectively, connected between the rail a and rail b_2 at opposite ends of the section. When there is no vehicle on the section, current circulates through the main windings h, h of the left-hand relay, causing the keeper j to rise and close the contact k . This connects the winding l of the relay armature, which is of high resistance, between the rail a and the signal main d . The relay armature is magnetized in such a direction that it is attracted by the right-hand pole piece of the relay, and closes contact m . In a similar way, the main windings i, i of the relay at the other end of the section are energized, and cause keeper j' to close contact k' , thus exciting the armature l' and closing contact m' . The circuit through the signal magnet n is also closed.

69. When the contacts m and m' , Fig. 35, of the relays connected to track section b_2 are closed, current can flow from the rail a through the valve-operating coils of signal n and train stop o in parallel, through contacts m' and m in series, and back to the signal main d by way of resistance p and wire q . Compressed air is admitted to the cylinders of the signal and train stop, and both are put in the clear position. When a car or train is in a block, as shown for section b_1 , the main windings of the relays connected to the section are shunted by the wheels and axles, and the relays are de-energized, opening the signal and train-stop circuits in two places, and allowing the signal and stop to go to the danger positions, as shown at n' and o' .

70. **Effects of Leakage Currents.**—The relays at the opposite ends of a section are so connected up that they cannot be both energized in the normal direction when a train is in the block. The possible conditions due to currents from other sources than the generator c , Fig. 35, may therefore be summarized as follows: (a) Both relays shunted. Normal condition. Circuit broken in two places. (b) One relay shunted, the other energized normally. Circuit broken in one place. (c) One relay shunted, the other energized reversely. Circuit broken in two places. (d) Both relays energized, one normally and one reversely. Circuit broken in one place. Under all these conditions the circuit is broken at one place at least, and the signal and train stop for the section remain in their danger positions.

71. **Length of Overlap.**—It is shown in Fig. 35 that a section does not end until some little distance after the stop-signal for the next block has been passed; in other words, there is a considerable overlap. In the system under consideration, the average length of the blocks on the busiest part of the line is 900 feet, and on other parts varies between 900 and 4,000 feet. The length of the overlap is 400 feet, this allowing ample space for the train to be brought to rest by the train stop. In a test on a train consisting of seven cars, travelling at full speed on a down grade of 1 in 460, the train was brought to a standstill in 218 feet, or a little more than half its own length.

A SERIES
OF
QUESTIONS AND EXAMPLES
RELATING TO THE SUBJECTS
TREATED OF IN THIS VOLUME.

The following Examination Questions are divided into sections corresponding to the text, so that each section has a head-line which is the same as that of the section to which the questions refer.

No attempt should be made to answer the questions or to solve the examples until the corresponding part of the text has been carefully studied.

TRAMWAY SYSTEMS

EXAMINATION QUESTIONS

(1) (a) What is understood by tractive effort? (b) Define tractive resistance.

(2) Name the five methods which have been used to supply current to electric tramcars.

(3) If a car increases its speed, in 15 seconds, from 5 miles per hour to 25 miles per hour, what is the average acceleration in miles per hour per second? Ans. 1.33 mi. per hr. per sec.

(4) (a) Distinguish between the geographical centre and the load centre of a tramway system. (b) How and when may these centres not be identical?

(5) For what reasons is it not generally feasible to drive electric cars from storage batteries carried on the cars themselves?

(6) Why does a tramcar require greater power during acceleration of speed than when running at a uniform speed?

(7) (a) What is understood by a gradient of 1 in 50? (b) What force, in addition to that necessary on a level track, is required to move a car weighing 15 tons uniformly up such a gradient? Ans. 672 lb.

(8) (a) What is the surface-contact system of supplying current to tramway cars? (b) Describe the working of the G.B. surface-contact system.

(9) What force, in addition to that required to overcome tractive resistance, must be applied to a car weighing 25 tons to give an acceleration of .9 mile per hour per second?

Ans. 2,295 lb.

(10) If it requires a force of 25 pounds per ton to move a car at a uniform rate on a level track, how many pounds per ton will be required to move it up a $3\frac{1}{2}$ per cent. gradient ?

Ans. 103·4 lb. per ton

(11) Why is direct and not alternating current always supplied to the trolley wire or other working conductor of a tramway, even though the transmission from the generating station to a substation may be by alternating current ?

(12) What are the following : (a) a yoke ? (b) a plough ? (c) a skate ? (d) a contact stud ?

(13) If it requires a tractive effort of 90 pounds per ton to start a given car on the level, what is the steepest incline on which it can be started without the wheels skidding, if 70 per cent. of the weight of the car rests on the driving wheels and the adhesive force is 14 per cent. of the weight on the driving wheels ?

Ans. 1 in 17, nearly

(14) (a) What are the special advantages of the conduit system of supplying current to tramway cars ? (b) What are the special disadvantages of the conduit system ?

(15) What precautions can be taken against leaving live studs behind the car in surface-contact systems ?

(16) If a car, with its passengers, weighs 12 tons, and the tractive resistance on the level is 20 pounds per ton, find the horsepower required to propel the car up a 5 per cent. gradient at a speed of 8 miles per hour.

Ans. 33·8 H.P.

(17) On a certain 500-volt tramway system six single-truck cars are to carry 45 passengers each and eight double-truck cars are to carry 75 passengers each. The single-truck cars weigh 9 tons and the double-truck cars weigh 15 tons each ; the passengers may be allowed for at 15 per ton, and the total loss between power station and the cars amounts to 20 per cent. of the power required for the cars. (a) What is the average current per car ? (b) How much power will be required at the cars ? (c) How much power must be generated at the station ?

Ans. $\left\{ \begin{array}{l} (a) \text{ 18 amperes and 30 amperes} \\ (b) \text{ 174 K.W.} \\ (c) \text{ 208·8 K.W.} \end{array} \right.$

(18) Sketch a diagram of connections and describe briefly a system of extra-high-tension generation and transmission and direct-current distribution to an overhead trolley wire.

(19) Summarize the principal considerations on which the best position of the power station, in regard to the tramway system which it supplies, is decided.

(20) Sketch and describe the path of current to and from a tramcar worked by the overhead trolley system, if the trolley wire is supplied at the voltage of the main generator.

TRAMWAY TRACKS

EXAMINATION QUESTIONS

(1) What are the most common gauges of track used for tramway work ?

(2) (a) Why are car wheels and rails made with bevelled tread ? (b) What are the standard weights per yard for rails of British Standard section ?

(3) What composition of steel is recommended by the Engineering Standards Committee for track rails ?

(4) What are tie-bars, rail anchors, and fish-plates ?

(5) Name four methods of making joints in track rails.

(6) What is a compound curve, and why does it give smoother riding than a simple curve ?

(7) Describe the thermit process of welding rail joints.

(8) What important point must be observed in laying out curves on double tracks ?

(9) (a) What is rail corrugation ? (b) How may the corrugation be removed ?

(10) Describe the method of making electrically welded joints in track rails.

(11) What special construction is adopted at points and cross-overs in tramway track in order to prevent excessive wear ?

(12) Calculate the resistance of 2 miles of double track consisting of rails weighing 100 pounds per yard, all four rails being in parallel.

Ans. .022 ohm

(13) Describe the method of making a Falk cast-welded joint in a track rail.

(14) What are the average values of the resistances of cast-welded, electrically welded, and thermit-welded rail joints in terms of lengths of solid rail?

(15) Enumerate the different types of paving in use for tramway tracks.

(16) (a) What are rail bonds, and why are they necessary?

(b) Describe three methods of expanding bond terminals into contact with the rail web.

(17) What is electrolysis, and under what conditions does it occur?

(18) Describe the principles of action of (a) the Siemens bond tester, (b) the telephonic bond tester, and (c) the Everett-Edgumbe bond tester.

(19) (a) For what purpose are negative feeders used?

(b) What is a negative booster, and how does it effect economy in feeder cables?

(20) Describe a method of electrically welding bonds to track rails.

TRAMWAY OVERHEAD WORK

EXAMINATION QUESTIONS

- (1) What are the two positions in which trolley wires are erected with regard to the track ?
- (2) Explain the construction of the tubular poles generally used for tramway work.
- (3) In what three ways are trolley wires generally supported ?
- (4) What are guard wires, and why are they used ?
- (5) Enumerate the advantages of the span-wire construction.
- (6) Explain how trolley wires are supported, so as to present a smooth surface to the trolley wheel.
- (7) (a) Of what material are trolley wires usually made ?
(b) What material is used for trolley wires where they have to withstand heavy wear ?
- (8) (a) When are frogs used ? (b) What is the difference between fixed and movable frogs ?
- (9) Describe the construction of a straight-line hanger.
- (10) (a) What special cross sections of trolley wire are sometimes used, and why ? (b) Are they entirely successful in practical working ?
- (11) What are double and single pull-offs, and for what are they used ?
- (12) Describe the order of procedure observed when erecting span and trolley wires.

(13) Explain the construction of: (a) Brooklyn insulators; (b) globe insulators. (c) Why will these insulators hold up the span wires even if their insulation is entirely destroyed?

(14) (a) Show two methods of erecting trolley wires at curves. (b) How are the wires anchored?

(15) (a) For what purpose are section insulators used? (b) Describe the construction of a section insulator.

(16) Describe the method which can be used by a single operator to produce artificial respiration in a person who has apparently been killed by an electric shock.

(17) What are the functions of a positive booster?

(18) Calculate the lowest voltage received by the cars on a system with eight equally spaced cars on a 3-mile length of double track, fed at the centre. The two trolley wires are each No. 00 S.W.G. and are connected in parallel. The rails are

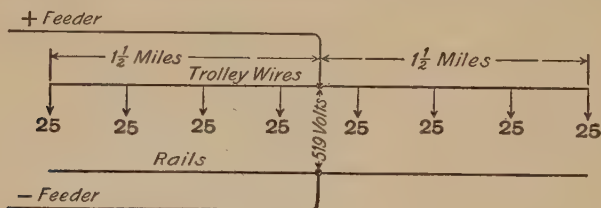


FIG. I

95 pounds per yard, and all four are in parallel. Each car is assumed to take 25 amperes. The system is arranged as shown in Fig. I, the voltage between the trolley wires and the rails at the feeding points being 519 volts.

Ans. 501.15 volts

(19) What is a feeder pillar, and what switches does it contain?

(20) Describe the principle and operation of the method adopted for rapidly testing the insulating fittings used on overhead work.

TRAMWAY CARS AND EQUIPMENT

EXAMINATION QUESTIONS

- (1) What is: (a) a trailer car? (b) a collision fender? (c) wheel base?
- (2) State the differences between single trucks and double trucks.
- (3) Describe the usual methods of lubricating trolley wheels.
- (4) Compare the special conditions for which single-deck and double-deck cars, respectively, are suitable.
- (5) What is the object of using car meters?
- (6) Describe briefly the different forms of motor suspension.
- (7) What is the best arrangement of car sheds and depots for a large tramway system serving a scattered district?
- (8) State the principal functions and requirements of a car truck.
- (9) What are the special uses of: (a) the fixed trolley head? (b) the swivelling head? (c) the self-righting head?
- (10) Describe the power circuit of a single-truck car that has a controller on each platform.
- (11) Describe the lighting circuit of a double-deck car.
- (12) Describe briefly the Pringle trolley-standard leakage indicator.
- (13) What are the special features of a compensating single truck?

(14) What is the purpose of the sliding contact sleeve as applied to a trolley head ?

(15) Describe the B.T.H. car lightning arrester.

(16) Describe the usual method of mounting and insulating resistance grids.

(17) Compare the relative properties of chilled-iron and steel-tired wheels for tramway work.

(18) Why is it usual to connect a canopy switch, automatic circuit-breaker, and fuse all in series in the trolley circuit ?

(19) Compare the relative advantages of the equal-wheel and maximum-traction trucks for different conditions of traffic and route.

(20) Describe briefly the action of the Westinghouse car circuit-breaker

BRAKES AND BRAKE RIGGING

EXAMINATION QUESTIONS

(1) Define (a) coefficient of adhesion and (b) coefficient of sliding friction.

(2) How can vacuum-brake exhausters be arranged to economize power when maintaining the train-pipe vacuum and to exhaust rapidly when releasing the brakes?

(3) State clearly the conditions under which the wheels of a moving car may be locked by the application of wheel brakes.

(4) (a) What is rheostatic braking? (b) Draw a simple diagram of connections suitable for rheostatic braking with two series motors.

(5) (a) Describe briefly one form of hand-brake rigging suitable for a single-truck car. (b) Illustrate the description by a simple sketch.

(6) (a) What are the three positions of the driver's combined switch and brake valve in the vacuum-brake system? (b) State briefly the operation of the brake gear in each position of the switch and valve handle.

(7) If a car is stopped in a distance of 100 feet after the brakes are applied, and if it is known that the car was traveling at a speed of 25 miles per hour when the brakes were first applied, what is the retardation? Ans. 6.73 ft. per sec. per sec.

(8) Why is an equalizing connection necessary between series motors when they are connected for rheostatic braking in the usual way?

(9) (a) Name the available systems of compressed-air supply for the compressed-air braking of electrically propelled trains.

(b) State briefly the advantages and disadvantages of the respective air-supply systems.

(10) If the weight per axle of a certain tramcar is 8 tons and the coefficients of adhesion of the wheels and of friction of the brake blocks are .25 and .2, respectively, what brake pressure per wheel may be expected to produce wheel slippage?

Ans. 11,200 lb.

(11) How is the operation of the wheel brakes affected by the use of (a) mechanical track brakes and (b) magnetic track brakes?

(12) What is the purpose of an arch bar, or curved transverse bar, as applied to a double-truck hand-brake rigging?

(13) Why must either the armature or the field connections of series motors be reversed when the motors are being used for rheostatic braking?

(14) Describe the principle and the method of operation of the Westinghouse electromagnetic brake, illustrating the answer by a simple sketch.

(15) Describe a hand-brake spindle that is designed to take up the slack of the brake-chain quickly and to apply the brake blocks strongly when they are in contact with the wheels.

(16) Can a tramcar descending a hill be stopped by an electric or electromagnetic brake? State reasons for answer.

(17) Explain why the usual arrangement of single-truck hand-brake rigging tends to apply the brake blocks more strongly on the rear than on the forward wheels.

(18) In connection with the compressed-air braking system for electric trains, describe briefly the purpose and operation of (a) the pump governor, (b) the feed-valve, (c) the auxiliary reservoir, and (d) the reservoir pipe.

(19) How does the use of the driving motors on a tramcar for electric braking affect the heating of the motors? State reason for answer.

(20) (a) What is the principle of regenerative braking? (b) Which class of direct-current tramway motor is suitable for regenerative braking?

TRAMWAY MOTORS AND CONTROLLERS

EXAMINATION QUESTIONS

(1) (a) What type of armature winding is used for tramway motors? (b) What are the advantages of the type of winding used?

(2) (a) What is the object of mechanically interlocking the power and reversing cylinders of a tramcar controller? (b) Describe briefly, with sketches, how the reverse cylinder of the Westinghouse T1 controller is prevented from moving except when the power drum is in the off-position.

(3) Compare the relative advantages of series-wound and shunt-wound motors for traction work.

(4) If the spur wheel of a certain reduction gear has 74 teeth and the pinion has 18 teeth, what is the numerical value of the gear ratio?

Ans. 4.11

(5) Explain the distinction between rheostatic and magnetic braking.

(6) (a) What is the star wheel of a controller? (b) What is its purpose?

(7) How is the rated output of a traction motor determined?

(8) Explain as simply as possible the principle of regenerative control.

(9) (a) What is a magnetic blow-out? (b) Why are blow-out magnets necessary?

(10) Why are motor cut-out switches provided on most series-parallel controllers ?

(11) What advantage has the series-parallel method of control over the rheostatic method ?

(12) Calculate the tractive effort of a motor when it is developing a torque of 470 pound-feet if it drives through a reduction gear the pinion of which has 18 teeth and the spur wheel 74 teeth, if the car wheels are 30 inches in diameter.

Ans. 1,546 lb., nearly

(13) Explain the action of the metallic-shield blow-out used on the Dick-Kerr controller.

(14) What will be the armature speed, in revolutions per minute, of the motor in question 12, when the car speed is 10 miles per hour ?

Ans. 461 R.P.M.

(15) Why are the pole pieces of traction motors usually laminated ?

(16) What are the advantages of fitting interpoles in a traction motor ?

(17) What are the relative advantages of oil and grease lubrication for the bearings (*a*) of the motor armature, and (*b*) of the car axle ?

(18) Explain how four motors are usually arranged for use with a series-parallel controller.

(19) Why are the armature leads interchanged in connecting to the reversing drums of the controllers at opposite ends of the car ?

(20) Describe fully the purpose and the method of connection of a lightning arrester on a tramcar.

DIRECT-CURRENT RAILWAYS

(PART 1)

EXAMINATION QUESTIONS

(1) (a) Some railways have both third and fourth conductor rails ; explain why this is done, and its advantages. (b) Where on the track are these conductor rails usually placed ?

(2) The efficiency of transmission on a certain electric railway from power house to the train is assumed to be 80 per cent. and the efficiency of the motor equipment is 75 per cent. What is the cost per brake horsepower-hour developed by the motors if the electric energy is purchased from the power house at .5d. per kilowatt-hour ? Ans. .6215d.

(3) Make sketches showing simple methods of sectionalizing (a) a trolley wire and (b) a third-rail conductor. (c) What is a train section ?

(4) A train weighs 100 tons and accelerates at the rate of 3 feet per second per second, the brakes being applied when it is travelling at 20 miles per hour ; another train of similar weight accelerates at one-half this rate and brakes are applied when it is travelling at $28\frac{1}{2}$ miles per hour. What is the kinetic energy of each train when the brakes are applied ? Ans. $\begin{cases} 2,992,170 \text{ ft.-lb.} \\ 6,077,357 \text{ ft.-lb.} \end{cases}$

(5) What advantage is there in supplying a train with current at a pressure of 1,100 volts as against 550 volts ?

(6) What is the usual limit of weight on the driving axles of locomotives, and why is it less on electric-motor coaches ?

(7) What tractive resistance, in pounds per ton, should be allowed for rolling stock : (a) for ordinary goods wagons ? (b) for

coal trucks and small wagons? (c) Why is it more economical to run coaches in trains rather than singly?

(8) Mention some of the factors that vary the amount of energy used by an electric train.

(9) What is the tractive resistance of a 9-coach train that weighs 200 tons when travelling at 20 miles an hour if the area of the coach front is 100 square feet? The constant for track friction is to be taken at 4 and the constant for journal friction at $\cdot 12$.

Ans. 7.52 lb. per ton

(10) The train-mileage of a certain railway is 4,000 per day. Half the trains weigh 140 tons each, and the other half 70 tons each. Allowing 70 watt-hours per ton-mile, what is the daily cost of electric energy if it is supplied at $\cdot 4d$. per kilowatt-hour?

Ans. £49

(11) A train weighing 120 tons runs at 21.6 miles per hour at the end of the acceleration period of 18 seconds. The rotational acceleration is taken as one-tenth of the translational acceleration, and tractive resistance is 10 pounds per ton; find the horsepower developed by the motors.

Ans. 1,000 H.P., nearly

(12) (a) Point out the differences between conditions on electric railways and tramways. (b) Define regeneration as applied to traction conditions.

(13) (a) Compare the acceleration of steam and electric trains. (b) What are the advantages of quick acceleration?

(14) (a) What is meant by the term coefficient of adhesion? (b) What is the maximum value for retardation with all wheels braked if the coefficient of adhesion is $\frac{1}{8}$?

(15) (a) What is the relation between forces for rotational and for translational acceleration? (b) What effect have curves on the tractive resistance of a train?

(16) Calculate the distance apart of two substations supplying current at a pressure of 580 volts to a third rail weighing 50 pounds per yard and 5 square inches cross-section. When the train is midway between the substations, it takes 1,400 amperes, and the electric pressure at that point is 500 volts. One-half the

drop is in the conductor and one-half in the track rails. The conductor rail has a resistance of .065 ohm per mile.

Ans. $1\frac{3}{4}$ mi., nearly

(17) Distinguish between the character of service required from the motor equipments of (a) urban electric railways; (b) suburban electric railways; (c) interurban electric railways; (d) main-line railways; (e) industrial railways; (f) shunting locomotives.

(18) The area of an ampere-seconds curve for the motor equipment of an underground railway is found to be 54,000 ampere-seconds. The weight of the train is 125 tons, and the distance covered during each cycle is 3,960 feet; find the energy consumption, in watt-hours per ton-mile, if the pressure is 500 volts.

Ans. 80 watt-hr. per ton-mi.

(19) Describe the various parts into which the cycle of operations performed by an electric train may be divided.

(20) (a) What are the effects of high acceleration on the generating station? (b) Why is it economical to use brakes in stopping a train?

DIRECT-CURRENT RAILWAYS

(PART 2)

EXAMINATION QUESTIONS

- (1) (a) How are conductor rails usually connected at the joints? (b) Why are welded joints not used?
- (2) In what way does the Dick-Kerr multiple-unit system of control differ from other multiple-unit systems?
- (3) Give a summary of the Board of Trade rules regarding trains on underground railways.
- (4) Describe briefly the advantage of using the coupling-rod type of electric locomotive.
- (5) Give a summary of the Board of Trade rules regarding the construction of underground railways.
- (6) Explain by the aid of a series of diagrams the bridge system of series-parallel control.
- (7) Give the principal features of the Dick-Kerr direct multiple control.
- (8) (a) Describe the link-suspended type of current collector. (b) What are the advantages of a bow collector?
- (9) What is the principal difference in the action of the British Thomson-Houston and Westinghouse contactors?
- (10) Describe briefly the principal types of railway motor suspensions.
- (11) Explain the use of the interlocks in the Westinghouse unit-switch control system.
- (12) Explain the method of rating railway motors.

(13) Explain the use of the dead man's handle used with the type M control.

(14) Explain by the aid of a diagram how the conductor rails are arranged at a junction of two tracks.

(15) (a) Of what materials are the insulators for conductor rails made? (b) Why are the rails not held rigidly to the insulators?

(16) Explain by the aid of diagrams how a motor coach in a train may be turned end for end and still retain the proper connections with the master controller.

(17) Explain the principle of the automatic-relay control.

(18) Explain the action of the metallic-shield blow-out coil.

(19) (a) Why is it necessary to have multiple-unit systems of control? (b) Explain the principle of multiple-unit control.

(20) (a) What are the advantages and disadvantages of gearless motors? (b) What two methods are used for supporting the armatures of gearless motors?

ALTERNATING-CURRENT RAILWAYS

(PART 1)

EXAMINATION QUESTIONS

(1) What method of overhead construction is generally used on three-phase railways?

(2) What is meant by regeneration, and in what way is it made use of in railways?

(3) What is the effect of inserting resistance in the rotor circuit of an induction motor?

(4) What considerations limit the voltage and frequency of the alternating-current supply for three-phase railways?

(5) Why will not a three-phase motor regenerate if the supply pressure fails?

(6) (a) Explain how two motors are connected in cascade.
(b) What effect does this method of connection have on their speed if their shafts are coupled together mechanically?
(c) What is the effect on the power factor?

(7) Describe the method of suspending the trolley wires adopted on the Valtellina Railway.

(8) An eight-pole motor and a six-pole motor have their shafts mechanically coupled, and are connected in cascade to a supply with a frequency of 25 cycles per second. At what speed will the combination run? Ans. 214·3 R.P.M., nearly

(9) How are the end driving wheels on the four-speed Simplon Tunnel locomotive arranged so that they can pass round curves easily ?

(10) What advantage do the new locomotives for the Simplon Tunnel Railway possess over the old locomotives for this railway ?

(11) For what reasons are squirrel-cage rotors sometimes used in motors designed to give speed variation by changing the number of poles on the stator ?

(12) What are the disadvantages of the rheostatic method of controlling the speed of a three-phase motor ?

(13) In what way are three-phase traction motors with squirrel-cage rotors started up ?

(14) What are the main differences between motors for stationary work and those for traction work ?

(15) What two considerations determine the resistance of squirrel-cage rotors for traction motors ?

(16) Describe with a simple sketch the coupling used on the motor coaches of the Valtellina Railway, to allow of relative movement between the rotor and the track wheels.

(17) Describe briefly the arrangement of circuits when the two motors of a three-speed Valtellina locomotive are connected in cascade.

(18) Explain how the driving bars are arranged on a three-phase locomotive so that the motors may be mounted on springs.

(19) Describe the method of starting a four-speed pole-changing locomotive.

(20) Describe the method of suspending the trolley wires on the Simplon Tunnel Railway.

ALTERNATING-CURRENT RAILWAYS

(PART 2)

EXAMINATION QUESTIONS

(1) Explain why a series motor will run in the same direction when the direction of the current passing through it is changed.

(2) How is the induced E.M.F. kept at a low value in the main field coils of a single-phase alternating-current motor?

(3) Why are preventive reactance coils used, and what effect do they have on the amount of current carried by each contactor or unit switch?

(4) What is the object of the compensating winding on the field frame of an alternating-current series motor?

(5) (a) How is the torque produced in a compensated repulsion motor? (b) How is the armature current produced?

(6) (a) Explain the purpose of the resistance leads between the armature coils and the commutator on some types of alternating-current series motors. (b) Why are commutating poles sometimes fitted to an alternating-current series motor?

(7) Mention two methods of operating the contactors of a unit-switch or multiple-control system.

(8) Describe briefly the Siemens catenary form of line construction.

(9) Explain why the power factor of the compensated repulsion motor increases as the speed increases.

(10) In connection with Fig. 36, state which contactors are closed on the first point of the master controller.

(11) In the single-catenary construction, how is the catenary cable usually supported and insulated?

(12) When a bow current collector or pantograph trolley is used, what is the object of placing the trolley wire alternately to the right and the left of the centre line of the track?

(13) How is the speed of the compensated repulsion motor controlled?

(14) Why is the equivalent resistance of a steel rail higher for alternating current than for direct current?

(15) What are the disadvantages of the ordinary form of double-catenary line construction, and how have these been overcome in the Siemens type of catenary suspension?

(16) Describe the Oerlikon type of current collector.

(17) Describe the stator construction of a modern alternating-current series motor.

(18) Calculate the equivalent resistance to alternating current at a frequency of 15 cycles per second of 3 miles of double track, composed of four rails in parallel, each rail weighing 100 pounds per yard.

Ans. $\cdot 1147$ ohm, approximately

(19) (a) For what purpose are sucking transformers used?

(b) Explain their action by means of a simple diagram.

(20) What are deflector wires, and for what purpose are they used?

ELECTRIC SIGNALLING ON RAILWAYS

EXAMINATION QUESTIONS

- (1) What are home and distant signals ?
- (2) What is (a) a telegraphic block system, and (b) a lock-and-block system ?
- (3) Explain briefly the principle of the staff and tablet systems of operating single lines.
- (4) What are automatic signals, and under what conditions are they necessary ?
- (5) Explain the construction and operation of the Siemens rail contact.
- (6) (a) What two types of block telegraph instruments are commonly used on telegraphic block systems ? (b) Explain their chief differences.
- (7) Show with simple sketches the positions and state the indications of home and distant signals mounted on the same post.
- (8) Explain the action of the Tyer signal replacer.
- (9) Enumerate the advantages of operating points and signals by power.
- (10) Explain how the signals are unlocked in the Sykes lock-and-block system.
- (11) What is the function of the check-lock on the operating lever of power-worked points ?
- (12) Explain the Sykes system of permissive signalling.

- (13) Explain the operation and use of a fouling bar.
- (14) Describe and explain the action of a signal selector.
- (15) Describe the construction of a light indicator.
- (16) Explain by the aid of a diagram the principle of track-circuit working of signals on a steam railway.
- (17) Why is extra safety secured by interlocking block telegraph instruments with the signal levers ?
- (18) For what purpose are signal reversers or replacers used ?
- (19) (a) What is the advantage in allowing one block or section to overlap another ? (b) What is the use of the automatic train stop ?
- (20) Make a diagram of the connections and describe the operation of the Westinghouse system of track circuits for electric railways.

ANSWERS
TO THE
QUESTIONS AND EXAMPLES
INCLUDED IN THE
EXAMINATION QUESTIONS.

Each Key, or set of Answers, has the same section number as the corresponding set of Examination Questions. All references are to the portion of the text that bears the same section number as the Key in which the references occur, unless the title of some other part of the text is mentioned.

To be of the greatest value, the Key should be consulted sparingly, much in the same manner as a pupil would go to a teacher for assistance in solving a problem he is unable to master unaided. The Key should not be referred to except as a last resource, when the student has failed, after using every reasonable effort, to solve the example or answer the question. If used in this way, the Key will be a help and a source of encouragement in studying the various subjects comprising the Course.

TRAMWAY SYSTEMS

(1) See Art. 36.

(2) See Art. 10.

(3) From Art. 43, acceleration is the rate at which speed is increased. As in 15 sec. the speed is increased from 5 to 25 mi. per hr., the rate of increase per second, or the acceleration, is $\frac{25 - 5}{15} = 1.33$ mi. per hr. per sec. Ans.

(4) (a) See Art. 59.

(b) See Arts. 59 to 64.

(5) See Art. 30.

(6) See Art. 43.

(7) (a) From Arts. 40 and 41, the steepness of a gradient may be expressed by the distance travelled along it in rising an equivalent vertical distance of 1 ft. Thus, a gradient of 1 in 50 means that there is a rise of 1 ft. in a distance of 50 ft. along the gradient. Ans.

(b) The weight of the car $W_c = 15$ tons, and the gradient $G = \frac{1}{50}$. Then, from formula 1, Art. 39, the additional force required to move the car uniformly up the gradient is

$$\frac{2,240 \times 15 \times 1}{50} = 672 \text{ lb. Ans.}$$

(8) (a) See Arts. 17 and 18.

(b) See Arts. 26 to 28.

(9) The weight W_c of the car is 25 tons, and the acceleration $A = .9$ mi. per hr. per sec. From formula 3, Art. 46, the additional force necessary to produce the given acceleration is

$$102 \times 25 \times .9 = 2,295 \text{ lb. Ans.}$$

(10) The tractive resistance equal to the tractive effort f on the level is 25 lb. per ton; the gradient $G_1 = 3\frac{1}{2}$, or 3.5 per cent. From the formula in Art. 41, the tractive effort per ton on the incline is

$$25 + 22.4 \times 3.5 = 25 + 78.4 = 103.4 \text{ lb. per ton. Ans.}$$

(11) See Arts. 7 and 8.

- (12) (a) See Art. 14.
 (b) See Art. 15.
 (c) See Arts. 10, 17, and 22.
 (d) See Arts. 10, 17, and 27.

(13) The tractive effort f' , or force per ton, required to start the given car on the level is 90 lb.; the ratio c of weight on the driving wheels to the total weight is $\frac{70}{100} = .7$; the ratio b of the adhesive force to the weight on the driving wheels is $\frac{14}{100} = .14$. Then, from the formula in Art. 50, the steepest incline on which the car will start is

$$.7 \times .14 - .00045 \times 90 = .098 - .0405 = .0575 = \frac{1}{17}, \text{ nearly 1 in 17. Ans.}$$

- (14) (a) See Arts. 14 and 15.
 (b) See Art. 16.

(15) See Arts. 17 to 25.

(16) The tractive resistance f on the level is 20 lb. per ton; the percentage of gradient $G_1 = 5$; then, from the formula in Art. 41, the tractive effort per ton required on the gradient is $20 + 22.4 \times 5 = 132$ lb. That is, the total force applied to the car is $12 \times 132 = 1,584$ lb. The speed, in miles per hour, $S = 8$. Therefore, from formula 2 in Art. 37, the horsepower required is $8 \times 1,584 \div 375 = 33.8$ H.P. Ans.

(17) (a) Allowing for passengers at 15 per ton, 45 passengers will weigh $\frac{45}{15} = 3$ tons, and 75 passengers will weigh $\frac{75}{15} = 5$ tons. The total weight of the single-truck car and passengers is $9 + 3 = 12$ tons, and of the double-truck car and passengers $15 + 5 = 20$ tons. Taking the average current, as given in Art. 53, as 1.5 amperes per ton of weight for a 500-volt system, the current for the single-truck cars is $12 \times 1.5 = 18$ amperes, and for the double-truck cars $20 \times 1.5 = 30$ amperes. Ans.

(b) On a 500-volt system, the power required per single-truck car is $\frac{18 \times 500}{1,000} = 9$ K.W., and for a double-truck car is $\frac{30 \times 500}{1,000} = 15$ K.W. Therefore, the total power required at the cars is

$$6 \times 9 + 8 \times 15 = 54 + 120 = 174 \text{ K.W. Ans.}$$

(c) If 20 per cent. of the power required at the cars is lost, the total loss is $\frac{174 \times 20}{100} = 34.8$ K.W., and the total power which must be generated at the power station is $174 + 34.8 = 208.8$ K.W. Ans.

- (18) See Art. 34.
 (19) See Arts. 58 to 64.
 (20) See Arts. 12 and 13, and Fig. 1.

TRAMWAY TRACKS

- (1) See Art. 2.
- (2) (a) See Art. 10.
(b) See Table II, Art. 7.
- (3) See Art. 4.
- (4) See Arts. 13, 15, and 18.
- (5) See Arts. 18 to 20, 23, 25, and 30.
- (6) See Art. 41.
- (7) See Arts. 30 to 34.
- (8) See Art. 42.
- (9) (a) See Art. 35.
(b) See Arts. 37 and 38.
- (10) See Arts. 25 to 29.
- (11) See Arts. 45 and 47.
- (12) From formula 3, Art. 59,

$$R_m = \frac{4.4}{W_y}$$

In this case $W_y = 100$; therefore,

$$R_m = \frac{4.4}{100} = .044 \text{ ohm}$$

The resistance of 2 mi. of single rail is thus $2 \times .044 = .088$ ohm,
and the resistance of 4 rails in parallel is $\frac{.088}{4} = .022$ ohm. Ans.

- (13) See Arts. 23 and 24.
- (14) See Arts. 62 to 64.
- (15) See Art. 50.
- (16) (a) See Art. 65.
(b) See Arts. 67 to 70.
- (17) See Arts. 85 to 89.

- (18) (a) See Arts. 79 and 80.
 - (b) See Arts. 81 to 83.
 - (c) See Art. 84.
- (19) (a) See Art. 93.
 - (b) See Art. 94.
- (20) See Arts. 71 and 72.

TRAMWAY OVERHEAD WORK

- (1) See Art. 1.
- (2) See Arts. 7 and 8.
- (3) See Arts. 2, 4, and 5.
- (4) See Art. 14.
- (5) See Art. 3.
- (6) See Arts. 20 and 21.
- (7) (a) See Art. 18.
(b) See Art. 19.
- (8) (a) See Art. 39.
(b) See Arts. 40 and 43.
- (9) See Arts. 26 and 27.
- (10) (a) See Art. 21.
(b) See Art. 22.
- (11) See Arts. 29 and 30.
- (12) See Arts. 50 to 52.
- (13) (a), (b), and (c) See Arts. 31 and 32.
- (14) (a) and (b) See Art. 54 and Fig. 41.
- (15) (a) and (b) See Art. 35.
- (16) See Art. 97.
- (17) See Art. 61.
- (18) The lowest voltage will be at the ends of the section. From Table VII, the resistance per mile of No. 00 S.W.G. copper trolley wire is .4527 ohm. From Art. 83, the distributed load behaves as if concentrated at $\frac{3}{4}$ mi. from the feeding point. Therefore, the resistance of trolley wires is

$$\frac{.4527 \times .75}{2} = .1698 \text{ ohm, approximately.}$$
 The drop in the trolley wires is $4 \times 25 \times .1698 = 16.98$ volts.

From Table IX, the resistance per mile of rails weighing 95 lb. per yd. is .0463 ohm. The resistance of the rails is therefore $\frac{.0463 \times .75}{4}$

$= .0087$ ohm, approximately. The drop in the rails is $4 \times 25 \times .0087 = .87$ volt. The total drop is $16.98 + .87 = 17.85$ volts. The lowest voltage received by the cars, therefore, is

$$519 - 17.85 = 501.15 \text{ volts. Ans.}$$

(19) See Art. 57.

(20) See Arts. 36 to 38.

TRAMWAY CARS AND EQUIPMENT

- (1) (a) See Art. 1.
(b) and (c) See Art. 4.
- (2) See Art. 6.
- (3) See Art. 36.
- (4) See Arts. 1 and 2.
- (5) See Art. 54.
- (6) See Arts. 18 to 21.
- (7) See Art. 63.
- (8) See Art. 6.
- (9) (a) and (b) See Art.
(c) See Art. 33.
- (10) See Art. 60.
- (11) See Art. 62.
- (12) See Arts. 58 and 59.
- (13) See Art. 9.
- (14) See Art. 32.
- (15) See Art. 57.
- (16) See Arts. 41 and 42.
- (17) See Arts. 24 and 25.
- (18) See Arts. 45 and 51.
- (19) See Art. 12.
- (20) See Arts. 47 and 48.

BRAKES AND BRAKE RIGGING

- (1) (a) and (b) See Art. 2.
- (2) See Art. 45.
- (3) See Art. 3.
- (4) (a) See Art. 21.
(b) See Art. 22 and Fig. 15.
- (5) (a) and (b) See Art. 7 and Fig. 3.
- (6) (a) and (b) See Art. 51.

(7) $S = 100$ ft.; $V = 25$ mi. per hr. $= \frac{25 \times 5,280}{3,600} = 36.7$ ft. per sec., nearly.

From the formula in Art. 5, $100 = \frac{36.7^2}{2a}$, or

$$a = \frac{36.7^2}{2 \times 100} = 6.73 \text{ ft. per sec. per sec.} \quad \text{Ans.}$$

- (8) See Art. 22.
- (9) (a) and (b) See Arts. 34 to 37.

(10) The weight per wheel $W = \frac{8 \times 2,240}{2} = 8,960$ lb.; $\mu = .25$.

Then, from the formula in Art. 2, $F = .25 \times 8,960 = 2,240$ lb. From Art. 3, the wheel slippage may be expected to commence when $F = F' = 2,240$ lb. But $\mu' = .2$. Therefore, the pressure of the brake block, or blocks, on each wheel will be

$$P = \frac{2,240}{.2} = 11,200 \text{ lb.} \quad \text{Ans.}$$

- (11) (a) and (b) See Arts. 15 and 25.
- (12) See Art. 9.
- (13) See Art. 22.
- (14) See Arts. 26, 27, and Fig. 18.
- (15) See Art. 13 and Fig. 8.
- (16) See Art. 23.
- (17) See Art. 8.

- (18) (a) See Art. 39.
(b) See Art. 43.
(c) See Arts. 42 and 44.
(d) See Art. 38.
- (19) See Art. 24.
- (20) (a) and (b) See Art. 24.

TRAMWAY MOTORS AND CONTROLLERS

- (1) (a) and (b) See Art. 4.
- (2) (a) See Art. 54.
(b) See Art. 87.
- (3) See Arts. 2 and 3.
- (4) See Art. 11. In the case given, the ratio is $\frac{74}{18} = 4.11$. Ans.
- (5) See Art. 79.
- (6) (a) and (b) See Art. 52.
- (7) See Art. 6.
- (8) See Arts. 95 and 96.
- (9) (a) and (b) See Arts. 55 and 56.
- (10) See Arts. 67 and 68.
- (11) See Art. 64.
- (12) From the formula in Art. 19, $F = \frac{24 F' r n'}{d'' n}$. In the case given,
 $F' r = 470, n' = 74, d'' = 30, n = 18$. Then,

$$F = \frac{24 \times 470 \times 74}{30 \times 18} = 1,546 \text{ lb., nearly. Ans.}$$
- (13) See Arts. 93 and 94.
- (14) By transposing the formula in Art. 21, it is found that the speed of the armature $s = \frac{336.1 \times n' \times S}{n \times d''}$. In the case given, $n' = 74, n = 18, S = 10, d'' = 30$. Substituting these values,

$$s = \frac{336.1 \times 74 \times 10}{18 \times 30} = 461 \text{ R.P.M. Ans.}$$
- (15) See Art. 1.

(16) See Art. 47.

(17) (a) and (b) See Art. 8.

(18) See Art. 77.

(19) See Art. 61. The armature wires are reversed on one controller, as shown in Fig. 26 of the text.

(20) See Art. 76.

DIRECT-CURRENT RAILWAYS

(PART 1)

(1) (a) See Art. 50.

(b) See Art. 44.

(2) See Art. 63. The combined efficiency is $\cdot 80 \times 75$ per cent. = 60 per cent. Therefore, for every brake horsepower-hour, the power house must deliver $\frac{746}{\cdot 6 \times 1,000} = 1\cdot 243$ K.W.-hr., which will cost $1\cdot 243 \times \cdot 5 = \cdot 6215$ d. Ans.

(3) (a) See Art. 54.

(b) See Art. 56.

(c) See Art. 55.

(4) From the formula in Art. 36, if one train runs at 20 mi. per hr.,
or $\frac{20 \times 5,280}{60 \times 60} = 29\cdot 33$ ft. per sec., its kinetic energy is

$$\frac{100 \times 2,240 \times 29\cdot 33^2}{2 \times 32\cdot 2} = 2,992,170 \text{ ft.-lb. Ans.}$$

If the other train runs at $28\frac{1}{2}$ mi. per hr., or $\frac{28\cdot 5 \times 5,280}{60 \times 60} = 41\cdot 8$ ft.

per sec., its kinetic energy is $\frac{100 \times 2,240 \times 41\cdot 8^2}{2 \times 32\cdot 2} = 6,077,357$ ft.-lb., or more than double that of the first train. Ans.

(5) See Art. 47.

(6) See Art. 41.

(7) (a) and (b) See Art. 11.

(c) See Art. 12.

(8) See Art. 35.

(9) From Art. 10, $A = 4$, $B = \cdot 12$, $C = \frac{\cdot 00035 \times 100 (7 + 9)}{200} = \cdot 0028$. Therefore, by the formula in Art. 10, the tractive resistance $D = 4 + (\cdot 12 \times 20) + (\cdot 0028 \times 20^2) = 7\cdot 52$ lb. per ton. Ans.

ALTERNATING-CURRENT RAILWAYS

(PART 1)

- (1) See Art. 94.
- (2) See Arts. 9 to 11.
- (3) See Art. 16.
- (4) See Arts. 4 and 5.
- (5) See Art. 13.
- (6) (a) See Arts. 19 and 20.
(b) See Arts. 21 and 22.
(c) See Art. 30.
- (7) See Arts. 95 and 96.
- (8) See Art. 21.

$$N = \frac{120 \sim}{P + P'} = \frac{120 \times 25}{8 + 6} = 214.3 \text{ R.P.M., nearly. Ans.}$$

- (9) See Art. 87.
- (10) See Art. 93.
- (11) See Art. 40.
- (12) See Art. 17.
- (13) See Art. 44.
- (14) See Art. 3.
- (15) See Arts. 42 and 43.
- (16) See Art. 59.
- (17) See Art. 77.
- (18) See Art. 66.
- (19) See Art. 92.
- (20) See Arts. 100 and 101.

ALTERNATING-CURRENT RAILWAYS

(PART 2)

- (1) See Art. 3.
- (2) See Art. 4.
- (3) See Arts. 62 and 63.
- (4) See Arts. 5 to 8.
- (5) (a) See Art. 46.
(b) See Art. 45.
- (6) (a) See Arts. 20 and 21.
(b) See Art. 22.
- (7) See Art. 60.
- (8) See Art. 131.
- (9) See Art. 49.
- (10) See Art. 100.
- (11) See Art. 121.
- (12) See Art. 116.
- (13) See Arts. 52 and 53.
- (14) See Art. 135.
- (15) See Arts. 125 and 131.
- (16) See Arts. 119 and 120.
- (17) See Arts. 37 and 38.
- (18) From formula 3, Art. 136, the equivalent resistance of 1 mi. of single rail is $R_{1s} = \frac{15.3}{100} = .153$ ohm, and that of 3 mi. of track, consisting of four rails in parallel, is

$$\frac{.153 \times 3}{4} = .1147 \text{ ohm, approximately. Ans.}$$

- (19) See Art. 138.
- (20) See Art. 130.

ELECTRIC SIGNALLING ON RAILWAYS

- (1) See Arts. 3 and 4.
- (2) (a) See Art. 7.
(b) See Art. 17.
- (3) See Art. 47.
- (4) See Art. 57.
- (5) See Art. 20.
- (6) See Art. 7.
- (7) See Art. 5.
- (8) See Art. 27.
- (9) See Art. 48.
- (10) See Art. 34.
- (11) See Art. 50.
- (12) See Art. 39.
- (13) See Art. 22.
- (14) See Arts. 31 and 32.
- (15) See Art. 28.
- (16) See Art. 66.
- (17) See Art. 17.
- (18) See Art. 24.
- (19) (a) See Art. 62.
(b) See Art. 63.
- (20) See Arts. 67 to 69.

INDEX

NOTE.—All items in this Index refer first to the section and then to the page of the section. Thus, *Adhesion*, §63, p34, means that *Adhesion* will be found on page 34 of section 63. When there are several items having the same key word, this is, for brevity, omitted after the first reference, and the other items are indented, or set in, from the left margin, to indicate this omission, which never consists of more than one word. Thus, under the key word *Air* is found the indented item, *supply*, *Systems of*; this is read *Systems of air supply*, the capitalization of *Systems* denoting the first word of the reference.

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